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THE ELECTRIC JOURNAL

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Electrical Progress in 1917

The keynote of the electrical industry during the past year has been production rather than development. This is a logical sequence of the general speeding up of specialized industrial production, with the resultant need of motors and of central station energy. In fact these two requirements, with the need of the central stations for additional generating equipment, have been so large as to preclude extensive attention to other considerations. Nevertheless there have been consistent detail refinements and improvements.

Perhaps the most spectacular development has been in the electrification of main roll drives of steel mills. Thirty-eight of these outfits were ordered during the year, one of which is the largest reversing mill equipment ever built. This motor has a maximum rating of 17 500 horse-power, and will drive a 60 inch universal plate mill for the Bethlehem Steel Company. In addition, large numbers of smaller motors for auxiliary drives bring the total average for the years 1916 and 1917 up to more than three times the value for the previous five years. While perhaps on a larger scale than any other, this increase is typical of the way in which electricity is solving production problems in all branches of industrial activity.

Even more spectacular than the increase in the use of electrical energy in any one industry, has been the steady increase along all lines, as evidenced by the tremendous growth of central station outputs in our industrial centers. This has been due not so much to increased numbers of power users, as to the increased power consumption of old customers. The result has been that, in some cases, the central stations have found themselves inadequately equipped to care for loads which have increased enormously, nearly 100 percent in twelve months in at least one case.

In view of the fact that the previous year's growth had been, in many cases, nearly double the usual normal growth of 12 to 15 percent, the possibility of a power shortage in some localities is not to be wondered at. That such tremendous loads are being carried with as little difficulty as they are, speaks well for the foresight and ability of our central station managers.

More generating units of large individual capacity have been contracted for during the past year than ever before. As typical examples, at Pittsburgh the Duquesne Light Company are installing a 40 000 kilowatt cross-compound unit; at Providence, the Narragansett Electric Company are installing a 45 000 kilowatt cross-compound unit; and at New York the Interborough Rapid Transit Company are installing a 70 000 kilowatt triple element unit.

One result of the heavy overloads with which most central stations have to contend, has been an unprecedented demand for forced draft underfeed stokers etc. These are being supplied both in connection with new equipments, and also in many cases to replace older forms of furnaces in order to obtain more capacity without any change in the old equipment.

The increase in the cost of coal has brought about a steady increase in hydroelectric generating stations. Among the larger installations is that of the Montana Power Company, at Holter, Montana, in which are installed four 12 000 k.v.a. vertical units. The power from this plant is used on the electrification of the Chicago, Milwaukee & St. Paul Railroad, which is largely increasing its electrified zone, and the saving in coal due to the use of this water power will be a very considerable item.

Another development brought about by the high cost of materials, labor, etc., and especially the high cost of copper, has been an increased tendency towards the use of synchronous condensers for both power-factor correction and voltage regulation. In many cases the installation of such apparatus saves an increase in transmission line copper, or allows additional load to be taken on a given transmission line, and at the same time maintains normal and satisfactory voltage conditions. Typical of this tendency is the case of the Duquesne Light Company who are installing three 7500 k.v.a. synchronous condensers for this purpose on their system in and about Pittsburgh.

In the electrification of steam railroads, the requirements for heavy freight traffic on mountain grade sections have been met by the production of a very powerful phase-converter locomotive having several improvements over those previously built. This locomotive, weighing 250 tons, has a capacity of 4800 horse-power and a maximum tractive effort of 130 000 pounds, all of which is concentrated in a single-cab unit. The most interesting improvement in this type of locomotive is the synchronous phase converter, by which 100 percent power-factor is obtained.

New high-voltage, direct-current, high powered passenger locomotives have also been developed. The rating of these locomotives is 4000 horse-power with a starting effort of 112 000 pounds, and a total weight of 266 tons. These engines will also be single-cab units.

Regenerative control for direct-current, has been perfected to such an extent that it is now applied whenever desired to 600 volt locomotives as a standard. This feature contributes very largely to safety in operation of electric locomotives. The development of the high-speed circuit breaker methods for suppressing flashing in high-voltage direct-current apparatus has also taken a forward step during the past year and the indications

are that this difficulty in machines of this class has been definitely suppressed. These detail developments have put the electrical industry in a position of preparedness for the more general electrification of railroads which, it is anticipated, will become very active in the near future.

The outstanding feature in the street railway field has been the stability in design of the present standard lines, permitting the railway companies to feel secure in establishing standards for future practice. The present standard railway motors and control outfits have been worked up to a point where improvements are extremely difficult, and the reports of their performance in service are very gratifying.

As in 1916 the outstanding feature of switchboard business for 1917 was the continued demand for switch gear for power stations of tremendous initial and ultimate capacity. Initial capacities of 66 000 k.v.a. and ultimate capacities of as high as 387 000 k.v.a. are represented in installations projected and for which switch gear was purchased during the year. Improvements have been made both in the major apparatus forming part of the switch gear and also in the smaller details. In the first class may be mentioned the completion of a number of 150 000 volt outdoor oil circuit breakers of rupturing capacities far in advance of anything heretofore within the limits of high voltage apparatus. With their guaranteed arc rupturing capacity, with voltage maintained, of 1 000 000 k.v.a., it is felt that the question of high-voltage power concentration is solved for at least some time. There has also been the development of a successful and simple control equipment for automatic rotary converter substations. One such outfit has been in successful operation for some time and others are under construction. To a very large degree the bulk and complexity characteristic of earlier control equipment for such installations has been eliminated.

Steam Turbine Development

An article by Mr. Francis Hodgkinson, entitled "A Historial Review of Steam Turbine Progress," which is begun in this issue, is the first of a group of articles constituting a continuance of a series which appeared during the years 1915 and 1916 under the general topic "Engineering Evolution of Electrical Apparatus." It has been thought that it would be of much interest to the JOURNAL readers if these discourses on various phases of steam power plant engineering were continued by engineers especially experienced in that direction.

Mr. Hodgkinson's contribution has the peculiar value that he has been identified with steam turbine work from its early inception as a thing of practical application. His recital of the early steps of development constitutes a first hand experience with the problems of that day. Nor is he less favored in his narration of the later progress leading up to the larger machines of today, for this work is still under his general direction.

Steam turbine development has been a subject of such importance that much literature on the subject has appeared, until one would suppose there is little to be said that is new in the way of a historical review. The present article, however, is of particular interest in that it brings us into rather intimate touch with the subject as the designer sees it. We are given a sort of inside view of the problems that were overcome, how designs were improved and how in particular a better knowledge of materials has helped so much to advance the art.

Finally, the author ventures the expectation that experience with different types and lay-outs of large turbine units will gradually result in the operators and builders alike agreeing upon a closer uniformity of standards and of arrangement. He thinks, after that, that any material future improvements will be in the direction of more efficient operating conditions, rather than in any particular betterment of thermal performance of the turbine itself.

Our central stations are becoming larger all the time. Generating units are growing into tremendous sizes, and so much depends upon them that reliability means more than it used to. Also, fuel will always tend to be more expensive, so the subject is one which will continue to require the best thought of builder and user alike.

E. H. SNIFFIN

A Logical Railway Development

We have been a wasteful and extravagant nation. Our development has been so rapid and our wealth of raw material so inexhaustible that the questions of economy and conservation have not heretofore been a factor in our progress. War has, however, brought us to a stern realization of the necessity of conservation and economy.

The railroads have been a prominent factor in the development of our industries and in opening up our vast areas to civilization. For this development to continue progressively, it is necessary that railroad facilities shall keep always ahead of the demand. We realize now that for the past ten years railroad expansion has not even kept pace with industrial growth. The railroads were caught in the net of governmental and political restriction, and constructive development was manacled by rate rulings, and unwise legislation, which deprived them of the surplus necessary for expansion, leaving them only the bare necessities for a precarious existence. We are now demanding, in order to relieve congestion and increase efficiency, that they do the very things we only a short time back passed laws to prevent.

This war has brought us to a realization of the value and necessity of the railroads and an appreciation of their worth to us. There is no doubt but that the active public demand will, therefore, soon be great enough to insure the readjustment of controlling legislation, so as to provide sufficient revenue for a renewal of their constructive program. When this time comes, we expect to see much activity along the lines of electrification, for the reasons which Mr. Wynne has so aptly pointed out in his admirable article in this issue on "Electrification of Railroads as a War Measure."

W. R. STINEMETZ

The Engineering Evolution of Power Plant Apparatus—XXIV

A Historical Review of Steam Turbine Progress

Francis Hodgkinson

ROUGHLY speaking, the whole of the development of the steam turbine has occurred within thirty years. This is a very brief period as compared with the development of the reciprocating engine, which occurred over a period of more than ninety years. Many are inclined to attribute this to the high technical skill and scientifical attainment of the present age, but a more true reason than this is the fact that metallurgical and manufacturing arts were available for the turbine manufacturer which were not available for the early builders of steam engines.

A cursory review of the British Patent Office records in the early years, say 1800 to 1850, show them to be rich in turbine inventions, and nearly every modern turbine principle and some others will be found exemplified. It is assumed that these ideas were abandoned because of the then apparently greater promise of the reciprocating engine and the undeveloped stage of machine shop practice which rendered production of efficiently shaped blades practically impossible.

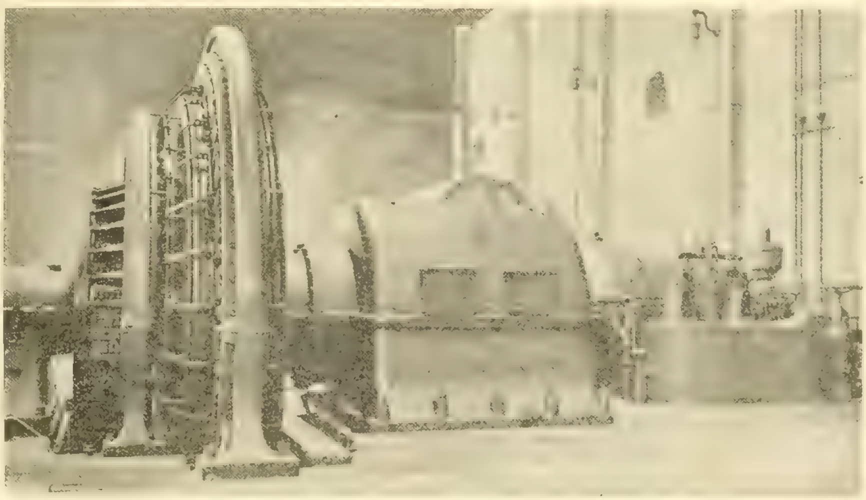

FIG. 1—3750 KW, 1800 R.P.M., NON-CONDENSING STEAM TURBINE

Driving 180 r.p.m. direct-current generator through a reduction gear, in the plant of the Cleveland Electric Illuminating Company. This unit has been in operation since 1912.

The steam turbine is generally regarded as of European origin, the reduction to useful practice having been carried out by Messrs. Parsons and DeLaval, and it is not generally known that steam turbines were commercially built in Syracuse, New York, as early as 1833. Several of these were sold and employed for driving saw mills, and were of the kind which might be described as of the "Hero" type, steam being admitted through the shaft and issuing tangentially from two radial arms. One user of these, Mr. N. Felt, of Cicero, New York, reported in 1835 that the turbine driving his saw mill used two-thirds the fuel of the reciprocator it replaced.

It is reported that in 1836 one of these was placed upon a locomotive near Newark, New Jersey. The turbine had an arm tip speed of 14.25 miles a minute. Its life was ended in a ditch. It is, however, interesting to record that Parsons built a precisely similar machine about 1890, comprising a single "Hero" element. Its capacity approximated 20 hp, and with 100 lbs. pressure and 26 inches vacuum, had a steam consumption of 40 lbs. per horse-power hour. His attempts to improve performance by compounding were unsuccessful because of the friction of the arms in the more dense fluid.

No historical review of the development of steam turbines would be complete without tribute to the work of Sir Charles A. Parsons, who, in spite of the many difficulties to be overcome, had the courage of his convictions and expended a large personal fortune in this work. He commenced work in 1884 by determining whether bodies could be operated at eighteen or twenty thousand revolutions per minute, and then proceeded to the building of a small turbine. The author is sure that Sir Charles at the outset thoroughly realized that the sphere of the steam turbine was in large sizes rather than small, but he had associated himself with a firm of engineers whose principal business was the equipping of ships with donkey boilers, winches, windlasses, etc., so it was natural that his activities were confined to the building of lighting sets for shipboard use. These sets were of small capacity, running at from fourteen thousand to eighteen thousand revolutions per minute, driving direct-current generators. The generators, while highly unsatisfactory from the standpoint of a modern direct-current machine, were remarkably ingenious in their design. It was not until he dissolved partnership with the above mentioned firm and established his own engineering works that he was enabled to build steam turbines and apply them to what he believed to be their proper sphere; viz., central station work. He applied them to the earliest central stations; viz., Newcastle, Cambridge, and Scarboro, in England in 1899, a 75 kw machine being furnished to the former city. Of

course, early progress was retarded by the small demand for high-speed machinery. Practically their only application was for driving dynamos which were then built only in small sizes.

During the period from 1884 to 1889 about 300 turbines were built, ranging up to 75 kw. In 1894 a number of 350 to 500 kw non-condensing turbines were built for driving 50 cycle generators at 3000 r.p.m. These were furnished to the various electric lighting companies in London and displaced both Willans and Westinghouse single-acting engines, as the company operating them had received an injunction on account of the vibration being a nuisance to the community, which was withdrawn with the installation of these turbines.

Sir Charles Parsons has been unrelaxing in his energy in the development of steam turbines, his efforts culminating finally in the construction of enormous turbines for direct connection to the propellers of express steamers, the engineering difficulties to be overcome in their construction being of a far higher order than that required for the most successful high-speed turbine for land service.

FIG. 2—3000 HP, 1500 R.P.M., LOW-PRESSURE STEAM TURBINE

Driving through reduction gears two, 125 r.p.m., Ingersoll-Rand gas pumps, which raise the pressure in the mains from 70 or 100 to 340 pounds. This unit has been in operation in the plant of the Hope Natural Gas Company since the summer of 1914.

In 1896, the steam turbine as a practical machine was almost unknown in the United States. A foreign built DeLaval turbine of 300 kw capacity had been furnished to the Edison Company of New York. A few Dow turbines of small capacity had been built, and while exceedingly ingenious in their character, they did not have much commercial application except for use in speeding up the flywheels of Howell torpedoes for the United States Navy.

At this time Mr. George Westinghouse realizing with his characteristic foresight the possibilities of the turbine, secured for the Westinghouse Machine Company the rights to manufacture them under a license from Sir Charles A. Parsons. In 1896 a 120 kw turbine was built in Pittsburgh of condensing design and drove a direct-current generator at 5000 r.p.m. This turbine had a water rate of 25.6 lbs. per kw-hr. operating with 160 lbs steam pressure and 27.1 inches vacuum. The turbine was regarded as entirely satisfactory, but it need hardly be said that the generator did not come up to standards of direct-current apparatus, even of that day. In the succeeding years the Westinghouse Machine Company was substantially alone in the turbine field; gas engines and large Corliss engines occupied most of the activities of the Company, so that until 1899 turbine development, except for some experimental machines, was practically at a standstill.

During the year 1899, the powerhouse of the Westinghouse Air Brake Company, Wilmerding, Penna., was equipped with three 400 kw turbines, which was the first serious turbine installation carried out in this country. The performance of these machines with 150 lbs. steam pressure, 100 degrees F. superheat, and 28 inches of vacuum was as follows:—

Load in Brake Horse-Power	Pounds Steam per Brake Horse-Power Hour
264	14.48
445	12.87
593	12.05
759	12.06

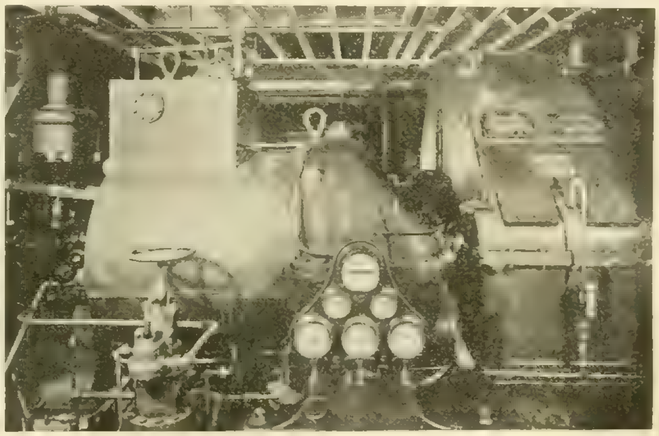

FIG. 3—1700 HP, 3000 R.P.M. COMPLETE EXPANSION STEAM TURBINE

The gear runs at 140 r.p.m. and is directly coupled to the mill shafting. This unit has been in operation in the plant of the Northwestern Consolidated Milling Company since the summer of 1917.

A quite historic turbine installation was made in 1900 at the plant of the Hartford Electric Light Company, Hartford, Conn., which was of 2000 kw capacity, running at 1200 r.p.m. This turbine was at least twice as large as any turbine that had ever been built, and caused much comment at that time. The whole of the expansion was carried out in a single cylinder. European turbine builders, commenting on this, regarded it as a courageous thing to attempt to build such a large turbine structure in one single cylinder, and here came about a crossing of ideas, which is not infrequent in engineering progress; viz., two groups of engineers each abandoning their own line of progress and adopting that of the other.

At this same time; viz., 1900, Sir Charles Parsons constructed the historic Elberfeld machine wherein the expansion of steam was carried out in two separate turbine cylinders coupled to each other tandem fashion. This machine, operating with 144 lbs. absolute steam

pressure, 26 degree F. superheat, and 28.2 inches of vacuum, gave a steam consumption of 19.0 lbs. per kw-hr. at 1250 kw load.

Sir Charles Parsons and also Brown Boveri of Basle, who had by that time become a licensee of Parsons, encouraged by the success of the American Hartford machine, proceeded to build large size turbines in a single cylinder, while we in America, being impressed by the reliability to be obtained from dividing the steam cycle of the turbine into two separate elements, proceeded to build several machines of from 1000 to 2000 kw capacity in two cylinders; these being constructed in 1903. Plainly two cylinder machines of such small capacities were expensive, but it is interesting to point out a reversion to this type, both by the General Electric Company and the Westinghouse Company, in the last two years. The Hartford machine above referred to

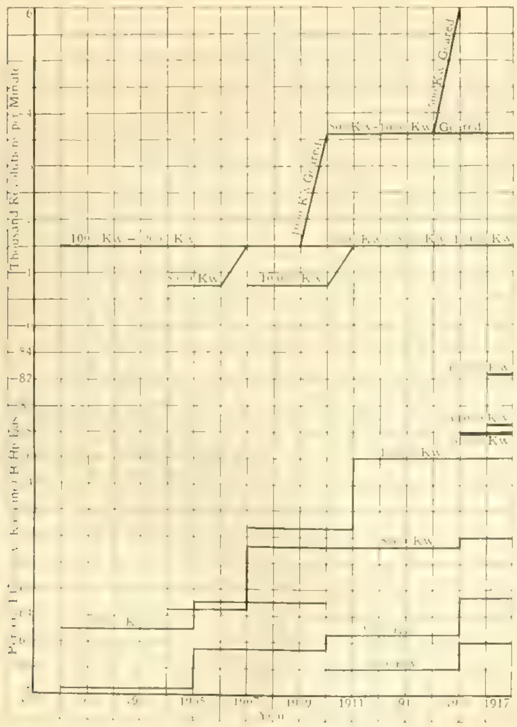

FIG. 4—GRAPHIC REPRESENTATION OF THE INCREASE IN EFFICIENCY OF STEAM TURBINE UNITS FOR 25 CYCLE OPERATION

caused sufficient interest that the General Electric Company saw their way to enter the turbine field and shortly thereafter commenced the construction of 5000 kw units for the Commonwealth Edison Company of Chicago.

Referring again to the two cylinder tandem turbines built in 1903; one advantage of the design was expected to accrue from the use of a reheating receiver between the two cylinders. Tests, however, showed clearly that the gain due to this did not warrant the expense, when high pressure steam was used for reheating. But the prophecy is ventured that there will be a reversion to intermediate reheating by means of separately fired superheaters for large machines in the near future.

The rapid strides made in central station practice in this country have brought about developments of turbines for land purposes in sizes that have gone beyond any European practice, and very remarkable steam engine performances have been obtained by the principal manufacturers. There is an impression that this development has, in this country, within the era say from 1900,

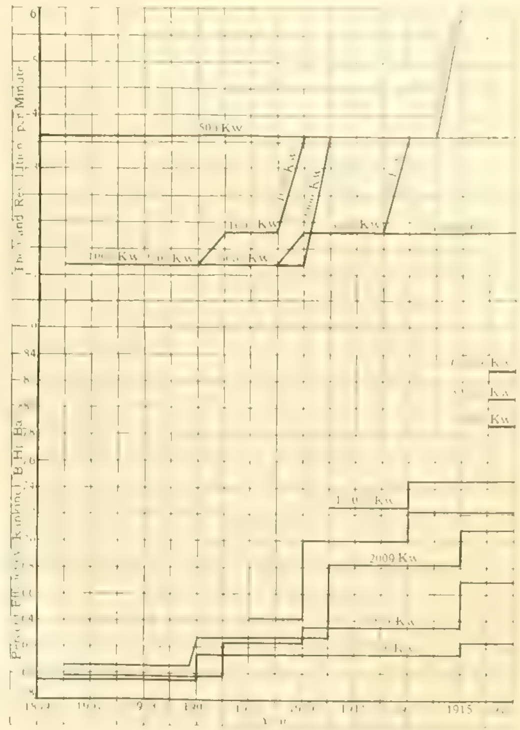

FIG. 5—GRAPHIC REPRESENTATION OF THE INCREASE IN EFFICIENCY OF STEAM TURBINE UNITS FOR 60 CYCLE OPERATION

grown from a very poor and uneconomical machine. This, however, is not true of the Westinghouse Company, for it is seen from the steam consumption of the earliest machines quoted and in what follows, that they do not compare very unfavorably with what can be done today with similar speeds and capacities. Unquestionably, improvements have been made in producing less

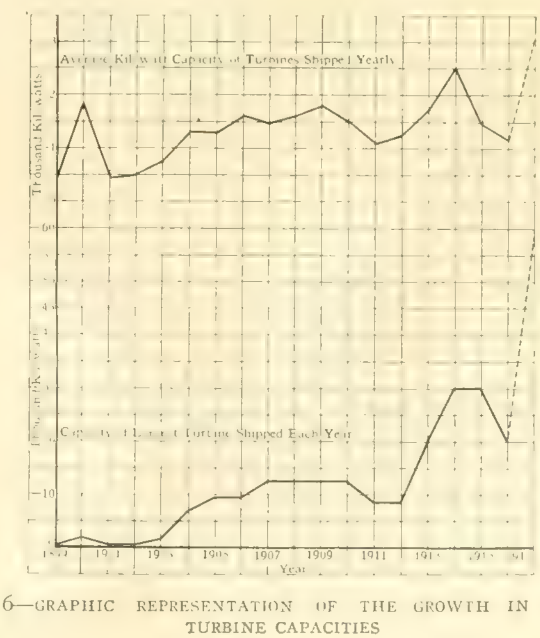

FIG. 6—GRAPHIC REPRESENTATION OF THE GROWTH IN STEAM TURBINE CAPACITIES

expensive and more reliable detail design. Improvements in economy, however, have been due to increased speeds for a given capacity rather than to any material change

of thought or principle as regards turbine systems. Very material advances have been made in the development of the high-speed alternating-current generators, which have permitted turbines to be designed more appropriately for the volumes of steam involved. Today, 5000 kw, 60-cycle machines have been built for operation at 3600 r.p.m., while in the year 1900 electrical engineers

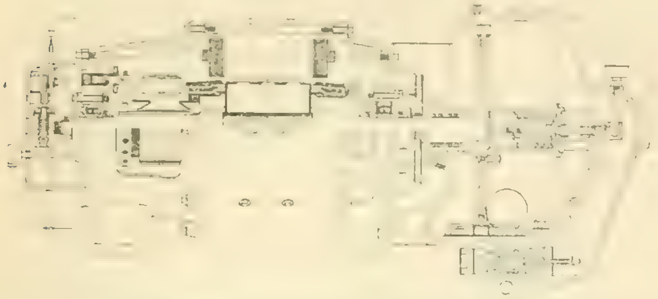

FIG. 7—NON-CONDENSING STEAM TURBINE OF THE RE-ENTRY TYPE
Direct-connected to a small direct-current generator.

looked askance at such speeds even for 500 kw units, and regarded 1800 r.p.m. as the more desirable speed for this capacity and frequency. Improvements in condensing apparatus have also contributed to the development of the turbine, bringing ordinary available vacua from 26 inches to 29 inches, this improvement having been brought about by the demands of the turbine builder, which were largely responded to by manufacturers of the more modern systems of condenser apparatus.

Today it may be said that the maximum capacities of generators at given speeds are as great as the capacities for which the turbine can be conveniently designed.

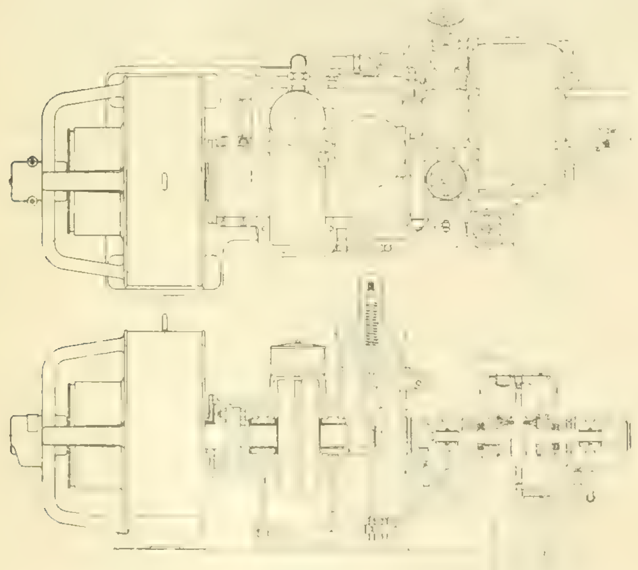

FIG. 8—NON-CONDENSING STEAM TURBINE OF THE RE-ENTRY TYPE
Geared to a direct-current generator.

signed. In other words, the turbine ceases to be a machine of too high speed for general application. It may be designed for its best speed and direct connected to the generator in the case of alternating-current machinery for all but the smaller sizes below 500 kw. It may be still operated at its most economical speed and by the intervention of toothed gearing be connected to direct-current generators or to other apparatus for any other purpose whatsoever, including direct mill drive, large reciprocating pumps and the propulsion of ships.

The principal field for the steam turbines has in the past been driving alternating-current generators; and as there are, broadly speaking, but two frequencies in conventional use in this country, 25 and 60-cycles, the speeds available were limited. Because of the difficulties

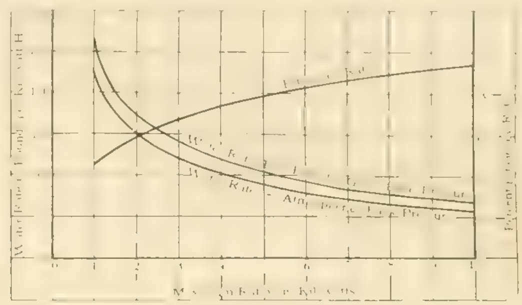

FIG. 9—PERFORMANCE CURVES
Of a 4000 r.p.m., direct-connected steam turbine unit, shown in Fig. 7, when supplied with dry, saturated steam at 175 pounds pressure.

of electrical transmission there has not been much demand for direct-current generators of large size. Further, because of the difficulty of designing direct-current generators for high speeds, the number of direct-current turbine installations is comparatively small. In the installations of direct-connected turbines and direct-current generators which were made, the speeds selected were too high for successful operation of the generators and too low for the economical operation of the turbines. Within the last eight years, however, reduction gears have been developed which remove this objection; so that today first-class designs of direct-current generators may be driven by turbines as successfully as can alternating-current units. A number of such

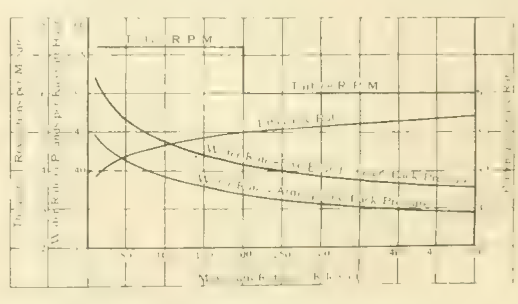

FIG. 10—PERFORMANCE CURVES
Of the geared steam turbine units shown in Fig. 8, when supplied with dry, saturated steam at 175 pounds pressure.

geared outfits have been installed, giving entire satisfaction, the speeds being as follows:

Capacity kw	Turbine Speed R.P.M.	Generator Speed R.P.M.
150	6000	900
300	6000	900
500	5000	720
1000	3600	514
1500	3600	300
3750	1800	180

The generator speeds given above are standard for motor-generator sets. Examples of important geared installations for purposes ordinarily considered outside the field of the steam turbine is given in Figs. 1 to 3.

The improvements which have been made in turbine performance since 1899 are shown by Figs. 4 and 5, for 25 and 60-cycles respectively. These curves show how speeds have been changed with the progress of time, each change of speed having been more productive of improved results than improvements in what are essentially turbine principles. The comparisons have been made on the basis of the efficiency ratio rather than steam consumption, because to make a comparison with the latter, the results would have to be reduced to a common operating condition, which would be improper. Should a high operating condition be selected it would not be fair to some of the older machines, which were hardly adapted to operate with high superheats and vacua, and the later machines would be at a disadvantage if their results were reduced to a low operating condition. The effect of the condenser on turbine development has been previously referred to. The improvement of condenser performance is directly attributable to the demands of the turbine. Early turbines had their low pressure elements designed to be suitable for vacua not much over 26 inches. All turbines nowadays are designed to expand steam at their point of best steam consumption to 29 inches vacuum.

Fig. 6 is of passing interest, showing the increase in the capacity of single units as built from year to year. The average capacity of turbines is also shown; it has not, however, been continuously an upgoing scale on account of the growth of business in single wheel impulse turbines of small capacity. In 1909 was commenced the development of small, single disc, non-condensing turbines of the re-entry type, intended primarily for the operation of condenser auxiliaries. Their general performance was so encouraging that in the course of time a line of excellent small machines suitable for electric generator drives, and also adaptable for driving any other kind of machinery, have been developed. The smaller ones, up to 15 kw are direct connected; above that they are geared. The general schemes of design are shown respectively in Figs. 7 and 8, and their performances in Figs. 9 and 10. The r.p.m. shown on the curves represent the speeds of the turbine shaft; the gear ratio being arranged to suit the driven machine.

Electrification of Railroads as a War Measure

F. E. WYNNE

TRANSPORTATION, whether by rail, water or highway is a most vital factor in prosecuting the war. The service demanded of the railroads of the United States by the present immense volume of traffic, largely due to the requirements of war, has demonstrated very clearly the inadequacy of our existing railroad facilities. Among the urgent necessities of the situation are larger and better arranged terminals, greater track capacity, increased train loads, higher speeds, more efficient motive power, and the conservation of fuel, materials and men. The practical patriotism which the railroads have displayed in combining management, facilities and equipment for the period of the war is accomplishing wonderful results of incalculable value. However, as the situation becomes more acute, through consumption of men and materials, other means may be necessary to secure the essential result.

The *Bulletin of the National City Bank of New York*, for November, 1917, on "Economic Conditions", contains the following comment:—

> "There is naturally a feeling of uncertainty and apprehension as to industrial conditions after the war. The demand for war materials will fall off, the supply of labor on the market will be greatly increased, and it is a question whether all of this labor can be promptly placed in employment. It will be the most stupendous reorganization of industry ever known, and it is going to be a great social problem to accomplish this change without confusion, loss of confidence and a period of stagnation. It is important that plans be laid on a large scale to take up the slack, and other countries are laying them. In this country, ready at hand, is the task of equipping the railroads, and other industries where practicable, to operate by electric power. * * * * * * * The amount of work in sight, if a general scheme of electrification was undertaken, would be sufficient to relieve the business community of its fears as to idleness and poor trade for some years to come, and would thus encourage other enterprises to go ahead.
>
> The danger will be in a pervasive feeling of uncertainty, causing men to wait with their own plans until they can discern the general trend, and waiting of itself slows down business. Large plans for the employment of labor which can be brought definitely forward at the critical time will serve to inspire confidence and support the whole situation."

It seems pertinent at this time, therefore, to consider seriously what electrification is capable of doing for the railroads now, at the same time bearing in mind the desirability of making definite plans for electrification when peace is finally secured. Conservation of fuel is highly important, not only in order to meet the extraordinary demands of our Government and the industries and for export to our Allies, but also because every reduction in fuel movement for domestic purposes adds to the equipment and track capacity available for moving export shipments. Electric operation lends itself to fuel conservation in two ways; either water power is substituted for steam power, or the necessary steam power is produced in a central power plant more economically than by burning fuel on locomotives. In the first case, all of the fuel used for train propulsion, fuel handling and haulage (which may be as high as ten per cent of the propulsion fuel), water pumping, etc. is saved for other purposes. In the second case, approximately one-half of the fuel is conserved, it being a well-established fact that one pound of coal burned in a modern electric power house will produce as much transportation as two pounds burned in steam locomotives.

The Government requirements for fuel oil are enormous and the supply is restricted on account of the reduced output from domestic fields, Mexican conditions and the fact that the Roumanian fields are in the possession of the Central Powers. Railroad electrification could relieve this situation considerably and water powers are already available or may readily be devel-

oped for the electric operation of many of the most difficult sections of the railroads now using oil-burning locomotives. However, the smaller fuel consumption now obtainable by the use of steam-driven stations is equally as important as the utilization of water powers, because the densest railroad traffic and the greatest congestion, is in territory within easy range of the best coal fields but where water power is scarce or extremely costly to develop.

At first glance, electrification may seem not to tend toward the conservation of materials. The construction of overhead lines; substations and possibly power stations calls for a large amount of material, a considerable proportion of which is copper and steel. On the other hand, fewer electric locomotives than steam locomotives are required to produce the same quantity of service. Where congestion is becoming unendurable, electric operation will give relief which, with the continuance of steam power, could be obtained only by building additional tracks and greatly increasing the steam motive power equipment. The steam locomotives re-

tion in the round house and shop labor of caring for and repairing motive power is found with electric locomotives. This is effected largely by the elimination of the boiler, firebox and tender which are essentials of the steam locomotive and by the longer time possible between "shoppings".

The combination of engine divisions, together with more exact and more reliable movement of trains with electric power makes possible a further conservation of man power by reducing the number of despatchers required to operate a given trackage. The indirect reduction in men comes chiefly through the fuel reduction or elimination. This releases men from mining coal or producing oil, from handling this fuel, and from operating and maintaining equipment in railroad fuel service, so that they are available for performing similar or other service in producing fuel and transportation for the needs of our Government, industries and Allies. Of course, all of the man power thus conserved is not a net gain, because the maintenance and operation of power house, substations, transmission and distribution

FIG. 1—HEAVY TRACTION LOCOMOTIVE PULLING A FULL TONNAGE TRAIN ON A MOUNTAIN GRADE

Two of these 270 ton locomotives, one pushing and one pulling, haul a 3250 ton train up a two percent grade at 14 miles per hour, and the front locomotive holds back the same train on an equivalent grade by regeneration with less than full-load current. For lighter trains a speed of 28 miles per hour can be obtained.

leased by electrification and the cars relieved from hauling railroad fuel take the place of new locomotives and cars for increasing the capacity of unelectrified divisions. It is apparent, therefore, that these features indicate the conservation of materials by means of electric operation.

Diverting millions of men from peaceful pursuits to war activities impose upon those remaining, the duty of working more efficiently. To this end, machinery must replace and release men to a greater extent than heretofore. Railroad electrification helps to conserve man power both directly and indirectly. Since it has been proven practicable to build, and operate with one engine crew, electric locomotives more powerful than steam locomotives, fewer enginemen are required to handle a given traffic electrically. Not only can larger trains be operated at higher speeds, but delays on the road are materially reduced and there is less overtime and little conflict with the 16-hour law. The operation of larger trains at higher speeds also decreases the number of train crews for a given traffic. Material reduc-

systems require the time and energies of some men not employed in the operation of a steam railroad. However, in any case, the net reduction in men required is great and increases more rapidly than in proportion to the extent of the electrification.

One of the greatest benefits derived from electrification is the increase in track capacity without laying additional rails. Probably there are few places where, under steam operation, the capacity of existing track could not be increased by the use of larger, more efficient locomotives, changes in train make-up, increased car-loading and modified operating conditions such as the "sailing dates" for l. c. l. freight recently introduced on certain railroads. All such improvements can be secured equally well with electric operation, and in addition still larger trains may be operated at higher speeds with greater safety and reliability and fewer delays. These results are obtained through the ability to concentrate in an electric locomotive greater power than in a single steam locomotive, to operate locomotives in multiple, and in the electric locomotive's smoothness

of control, its greater availability for service, the greater mileage between overhauling periods, the reduction in railroad fuel handled, the less serious nature of road failures, the elimination of intermediate engine terminals, and the definite speed of operation on the road. The movement of trains at higher speeds with fewer delays and less damage enables greater mileage to be secured from cars in a given time. This saves time in furnishing any quantity of transportation service and the time thus conserved is equivalent to increasing the number of cars available for service. In fact, it is more than equivalent, for there is less likelihood of congestion in handling a certain traffic with 1000 cars than if 1200 cars are required to accommodate the same traffic.

The *National City Bank Bulletin* for December, 1917, contains the following:—

> "The industries cannot expand beyond the limits fixed by the supply of pig iron, coal and railway service. If government funds can be used to remedy this situation it will be the most effective use to which, at this time, they can be applied. Here is the narrow place in the road, and if it can be widened, the energies of the country will produce immensely greater results."

FIG. 2—A HIGH-SPEED PASSENGER LOCOMOTIVE PULLING AN ALL STEEL TRAIN INTO PENNSYLVANIA TERMINAL STATION, NEW YORK

In regular service, these locomotives start 850 ton trains on a two percent grade, and are equally adaptable to passenger service at 60 miles per hour, and to light switcher service. The motors are rated at 4000 hp maximum.

Electrification is admirably adapted to "widening the narrow places" in the railroads. The greatest congestion, aside from terminals, occurs on roads handling ore, fuel, grain and munitions. The suggested use of government funds (where necessary) to assist in relieving this congestion appears to be both legitimate and logical. Government assistance might be secured in getting priority of manufacture also, since the apparatus to be built would be utilized to improve transportation facilities largely for government business. The manufacture of a number of electric locomotives would release a much larger number of steam locomotives and take some of the present burden from the steam locomotive factories by reducing the number of boilers, tenders, engine frames and running gears which such factories would have to build for a given amount of relief.

Not only must maximum capacity of existing facilities be secured but increased facilities at the weak points of our transportation systems should be provided with the utmost speed. Labor should be diverted from non-essential channels to the construction of these additional facilities. The diversified character of the materials and apparatus used and the greater service obtained from equal weight of material in electrical service make it practicable to secure a definite increase of

FIG. 3—SINGLE-PHASE LOCOMOTIVE FOR RELIEVING TUNNEL CONGESTION

These 130 ton locomotives haul passenger or freight trains with steam locomotive fires banked, through the five mile Hoosac Tunnel. Passenger trains now go through this tunnel with the windows open in summer time. Whereas only one steam operated passenger train was allowed in the tunnel at a time, three trains in each direction are now allowed in the tunnel simultaneously.

railroad facilities with electrification more readily than by building additional tracks, widening tunnels and bridges and building additional steam locomotives. Incidentally, in many cases, electrification is economically the best method of securing such increase in track capacity. It appears, therefore, that intelligent consideration of the present situation, the probable duration of the war and the future of the country, carried on jointly

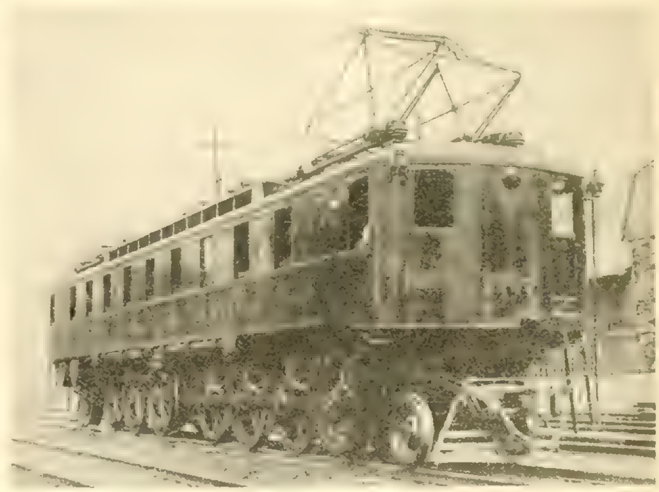

FIG. 4—THE MOST POWERFUL LOCOMOTIVE IN THE WORLD

For main line freight haulage on the Pennsylvania Railroad. Two of these 250 ton locomotives will haul a 3900 ton train up a 12 mile, two percent grade at 20.6 miles per hour. While nominally rated at 4800 hp, each locomotive will exert a starting tractive effort of 130 000 pounds, corresponding to maximum rating of 7000 hp. Through a synchronous phase converter, its three-phase induction motors draw single-phase current from the trolley at unity power-factor.

by our Government and the railroads, should lead to some electrification immediately and to the more extensive application of electric power to railroads when peace comes.

The Essentials of Transformer Practice - VI

Regulation

E. G. Reed

MAGNETIC LEAKAGE has already been referred to as being the cause of an eddy current loss in the conductors, but no reference was made to another phase of this leakage, which is the introduction of an element affecting the regulation of the transformer. The number of leakage lines flowing in a given transformer is largely dependent upon the relative position of the primary and secondary windings. Assuming, for instance, a transformer whose primary and secondary windings could occupy the same space, the primary winding would tend to establish a leakage field in one direction and the secondary to establish a leakage field in the opposite direction, resulting in the non-existence of an actual leakage field. If now the primary and secondary coils be separated, the forces tending to establish fields around the coils, no longer being coincident and no longer completely annulling each other, set up actual leakage fields. Thus if the coils were sufficiently separated, none of the lines of force from the primary coil will reach the secondary, in which case all of the lines through the primary winding will be leakage lines. The leakage fluxes from the two coils produce an effect which is additive and it is allowable, for the sake of simplicity, to think of all of the leakage lines as encircling the primary winding instead of being divided between the two parts. The equivalent leakage flux through the primary coil produces a counter electromotive force, which absorbs part of the impressed electromotive force. It is evident that this part of the impressed electromotive force does not reach the secondary winding and, therefore, its magnitude is a measure of the magnetic separation of the windings. The counter e.m.f. due to the leakage flux, is at right angles to the counter e.m.f. due to the normal flux in the magnetic circuit at no load. This of course, assumes that the load current is in phase with the terminal voltage; that is, that the transformer is delivering current to a non-inductive load. The phase relation of the counter e.m.f. due to the normal flux in the magnetic circuit at no load, becomes evident when it is considered that the leakage flux is in time phase with the primary load current, which in turn is displaced 90 degrees in time phase relation from the normal flux in the magnetic circuit at no load.

If the secondary of a transformer, the resistance of whose windings is negligible, be short-circuited, the voltage delivered to the load becomes zero and the voltage impressed on the primary winding is only that required to balance the counter e.m.f. due to the leakage flux. The voltage in this case, when normal full-load current flows through the short-circuited secondary, becomes the measure of the magnetic separation of the windings. Of course a transformer winding has resistance and in this test the impressed voltage is partly used in sending full-load current through this resistance. Considering the short-circuited transformer as an inductive coil, the impressed voltage required to drive full-load current through its windings is its impedance voltage. This impedance drop may be resolved into two components at right angles to each other, the one in time phase relation with the current being the resistance drop through the windings and the second being the reactive element which results from the magnetic leakage. The percent impedance of the transformer is the impedance voltage expressed as a percentage of the normal voltage of the winding upon which the impedance volts drop was determined. The percent reactance of a transformer, is the reactive volts drop expressed as a percentage in a similar manner. The percent reactance cannot be measured directly but must be calculated from the percent impedance drop, the percent drop in phase with the current and the known relation between these three quantities. The percent voltage drop in phase with the current has the same value as the total copper loss, expressed as a percentage of the k.v.a. output rating of the transformer.

CALCULATION OF TRANSFORMER REACTANCE

It is sometimes necessary to know the percent reactive drop, when the impedance value is not known. The following method of approximating this reactance, from the constants of the transformer, is only approximate, as certain assumptions must be made as to the length and section of the leakage paths which are not exact. The method applies particularly to the concentric type of winding shown in Fig. 1, but the same method can be applied to the interleaved type of winding.

Since the currents in the high and low-tension windings of a transformer are opposite in time phase relation, at each point along the gap separating them there is a magnetomotive force equal to the ampere-turns in either winding tending to produce a magnetic flux through the gap. This m.m.f. is, *0.4 I T*, *I T* being the ampere-turns in either winding. The reluctance of the leakage path is, $\frac{l}{l_g\, g}$, l being the length of the leakage path, l_g the mean turn of the gap between windings and g the width of the gap. The flux through the gap is,—

$$\Phi_g = 2.54 \frac{4\pi}{10} \frac{I\,T\,l_g\,g}{l} \qquad \text{.......................... (1)}$$

The constant 2.54 permits the linear distances to be expressed in inches instead of centimeters. This flux is in phase with the current in the winding and is therefore 90 degree in time phase relation from the flux producing the terminal voltage. As stated before, the leakage flux may be thought of as giving rise to an effect equivalent to an inductance connected in series with the

transformer. By definition the inductance L of a coil, in c.g.s. units, is equal to the flux which will be produced through the coil by unit current. Therefore, when L is expressed in henrys,—

$$L = \frac{10\,\Phi\,T}{10^9\,I}$$

Substituting the value of Φ in this expression from equation (1) gives,—

$$L = \frac{32.0}{10^9}\frac{T^2}{l}\,l_g\,g$$

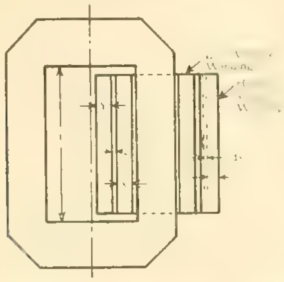

FIG. 1—SECTION THROUGH A CONCENTRIC WINDING OF A CORE-TYPE TRANSFORMER

This gives a reactance voltage of $e = 2\pi f L I$ or,—

$$e = \frac{200}{10^9}\,\frac{f T^2 I}{l}\,l_g\,g$$

Expressing this as a percentage of the voltage E of the transformer gives,—

$$\begin{array}{l}\textit{Percent reactance}\\ \textit{for flux through air-gap}\end{array} = \frac{2}{10^5}\;\frac{f\,T^2 I}{l\,E}\,l_g\,g \;\ldots\ldots(2)$$

The m.m.f. tending to produce leakage through the windings is a maximum at the inner edges adjacent to the gap between them and decreases to zero at the outer edges. Between these limits, it is proportional to the distance from the gap. As in the discussion of eddy current loss, it is assumed that there are two main paths of the leakage flux in the windings, one returning through the magnetic circuit and one being entirely within the coil itself. Consider first the leakage path which returns through the magnetic circuit of the transformer. The m.m.f. acting on the small section of the primary windings of width dx shown in Fig. 1, is $\frac{4\pi}{10}\frac{x}{Y}I\,T$. The reluctance of this leakage path is $\frac{l}{l_p\,dx}$ where l_p is the mean turn of the primary winding. Then,—

$$d\Phi_p = 2.54\,\frac{4\pi}{10}\,\frac{x}{Y}\;I\,T\,\frac{l_p}{l}\,dx$$

This flux encircles the fractional part $\frac{x}{Y}$ of the turns of the coil and therefore the fractional part $\frac{x}{Y}$ of the flux should be counted as encircling the entire coil, so that,—

$$d\Phi_p = 2.54\,\frac{4\pi}{10}\,\frac{x^2}{Y^2}\;I\,T\,\frac{l_p}{l}\,dx$$

or

$$\Phi_p = 2.54\,\frac{4\pi}{10}\;I\,T\,\frac{l_p}{l\,Y^2}\int_0^Y x^2\,dx$$

or

$$\Phi_p = 2.54\,\frac{4\pi}{10}\,(I\,T)_p\,\frac{l_p}{l}\,\frac{Y}{3}$$

It has been assumed that the mean turn of the sectional area of width dx, has a constant length equal to the mean turn of the coil. This assumption will not introduce an error greater than that to which the final result is subject, due to the uncertainty regarding the length of the leakage path. Similarly the leakage flux through the primary coil is,—

$$\Phi_s = 2.54\,\frac{4\pi}{10}\,(I\,T)_s\,\frac{l_s}{l}\,\frac{X}{3}$$

The percent reactance due to this leakage flux through the windings may be determined in the same manner as used for deriving equation (2) as follows,—

$$\begin{array}{l}\textit{Percent reactance}\\ \textit{for flux through primary}\end{array} = \frac{2}{10^5}\;\frac{f\,(I\,T^2)_p}{l\;E_p}\;\frac{l_p\,Y}{3}\;\ldots\ldots(3)$$

$$\begin{array}{l}\textit{Percent reactance}\\ \textit{for flux through secondary}\end{array} = \frac{2}{10^5}\;\frac{f\,(I\,T^2)_s}{l\;E_s}\;\frac{l_s\,X}{3}\;\ldots\ldots(4)$$

Since, $\frac{(IT^2)_p}{E_p} = \frac{(IT^2)_s}{E_s}$ equation (4) may be written,

$$\begin{array}{l}\textit{Percent reactance}\\ \textit{for flux through secondary}\end{array} = \frac{2}{10^5}\;\frac{f\,(IT^2)_p}{l\;E_p}\;\frac{l_s\,X}{3}\;\ldots\ldots(5)$$

Adding equations (2), (3) and (5), gives the total percent reactance of the transformer due to the leakage paths which return through the magnetic circuit as,—

$$\begin{array}{l}\textit{Total percent reactance}\\ \textit{for flux returning}\\ \textit{through magnetic circuit}\end{array} = \frac{0.667\,f\,IT^2}{10^5\;l\;E}\,(3\,l_g\,g + l_p\,Y + l_s\,X)\;\ldots(6)$$

It will be noted that l_sX, l_pY and l_gg are the areas of the secondary winding, primary winding and duct respectively, at right angles to the path of the leakage flux. This will suffice to outline the procedure in case the windings or ducts are not uniform in thickness.

In addition to this leakage flux, whose path is partly in air and partly in the magnetic circuit, there are additional leakage lines in the coils themselves whose paths do not enter the magnetic circuit. The effect of such lines is much less than that of the leakage approximated by equations (3) and (4). The reactance due to the

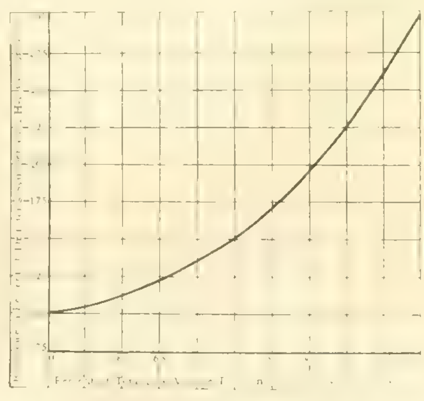

FIG. 2—EFFECT ON THE REACTANCE OF A CONCENTRIC TRANSFORMER WINDING

Produced by changing from a symmetrical to an unsymmetrical coil grouping. The total thickness of the low-voltage winding remains constant and equal to the thickness of the high-voltage winding.

leakage in the coils themselves, can be approximated by the same method as used for the main leakage flux. Making the same assumptions as when calculating the eddy current loss due to leakage flux through the windings,* the flux through a small path dx in the coil is,—

$$d\Phi_p = 2.54\,\frac{4\pi}{10}\,\frac{l_p}{l\,Y}\;I\,T\,\frac{K^2}{1+K^2}\,dx$$

*In the JOURNAL for Aug. '17, p. 308.

Since this flux encircles the fractional part $\frac{4Kx^2}{lX}$ of the total turns, this fractional part of the total flux should be counted as encircling the entire coil, therefore,—

$$d\Phi_p = 2.54\,\frac{4\pi}{10}\left(\frac{4K^3}{1+K^2}\right)\frac{l_p}{l^2 Y^2}\,IT\,x^3\,dx$$

or

$$\Phi_p = 2.54\,\frac{4\pi}{10}\left(\frac{4K^3}{1+K^2}\right)\frac{l_p}{l^2 Y^2}\,IT\int_0^{\frac{Y}{2}} x^3\,dx$$

or

$$\Phi_p = 0.100\left(\frac{K^3}{1+K^2}\right)\frac{l_p Y^2}{l^2}\,IT$$

For the values of K ordinarily existing in transformers, $\frac{K^3}{1+K^2}$ may be written as K, then,—

$$\Phi_p = 0.100\,IT\,\frac{l_p}{l}\,Y$$

Following the same procedure as before,—

$$\textit{Percent reactance for flux within secondary} = \frac{0.125}{10^5}\,f\,\frac{IT^2}{lE}\,l_p\,Y$$

$$\textit{Total percent reactance for flux within windings} = \frac{0.125}{10^5}\,f\,\frac{IT^2}{lE}\,(l_p Y + l_s X)$$

The total reactance is therefore,—

$$\textit{Total percent reactance} = \frac{f\,IT^2}{10^5\,lE}\Big[2\,l_g\,g + 0.79\,(l_p Y + l_s X)\Big]\ldots\ldots(7)$$

From the above it is evident that the part of the reactance due to the leakage flux through the coils and returning in the magnetic circuit is more than five times as large as the part due to the leakage flux within the windings. In order to obtain the total reactance of a transformer winding, the reactance of each high-low group must be calculated separately and the results added. A transformer winding may be composed of a number of H-L groups; for example, if the winding is composed of a high voltage coil between two low-voltage coils, the winding is said to have a 2 H-L coil grouping, the number of H-L groups being the number of times the high and low voltage coils are adjacent to each other. Increasing the number of H-L groups, decreases the magnetic leakage and thus reduces the eddy current loss and the transformer reactance. This is largely due to the ampere turns producing leakage flux being distributed and not concentrated as with a single H-L grouping. The curve in Fig. 2 gives an idea as to the variation of the reactance of a given transformer, with change of the grouping. It is assumed that the total coil thickness remains constant, as well as the relative thickness of the high and low voltage coils.

Example:— What is the percent reactance of a 50 k.v.a., 2300 to 230 volt, 60 cycle transformer, having the following constants? This transformer has a 2 H-L winding group, but for the sake of simplicity we will calculate the reactance for one of the groups only, taking the mean turn of the air-gap as the average of the two gaps.

$f = 60$	$l_s = 26$	$Y = 1$
$T = 200$	$E = 2300$	$l_g = 30$
$I = 21.8$	$X = 1$	$g = 0.2$
$l = 10$	$l_p = 34$	

Percent reactance =

$$\frac{60 \times 21.8 \times 200^2}{10^5 \times 10 \times 2300}\Big(2 \times 30 \times 0.2 + 0.79\,(34 \times 1 + 26 \times 1)\Big) = 1.36$$

Assuming that the reactance of both H-L groups is the same, the total reactance would be 2.72 per cent.

TRANSFORMER REGULATION

The regulation of a transformer is defined as the drop in secondary voltage, from no-load to full load, in terms of the full-load voltage. In the calculation of transformer regulation, there are three different conditions of load which must be considered. These are,—

1—With load of unity power-factor.
2—With load of lagging power-factor.
3—With load of leading power-factor.

With a load of unity power-factor, the relation of the various factors involved is shown in Fig. 3, where E_1 is the secondary voltage at no load and E_2 the secondary voltage at full load. The quantities IR, IX and IZ are the resistance, reactance and impedance drops in the transformer at normal load in terms of its characteristics as referred to the secondary side. By definition,—

$$\textit{Regulation} = \frac{E_1 - E_2}{E_2} = \frac{AF}{E_2} = \frac{AC + CF}{E_2}\ldots\ldots\ldots\ldots(8)$$

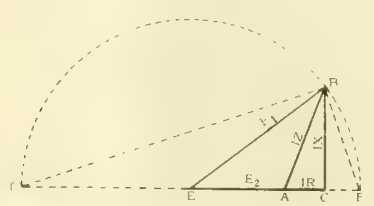

FIG. 3—REGULATION DIAGRAM FOR LOAD OF UNITY POWER-FACTOR

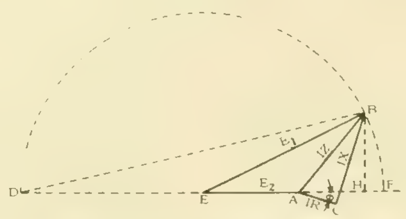

FIG. 4—REGULATION DIAGRAM FOR LOAD OF LAGGING POWER-FACTOR

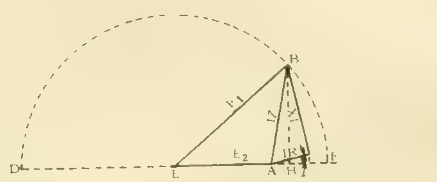

FIG. 5—REGULATION DIAGRAM FOR LOAD OF LEADING POWER-FACTOR

In equation (8), AC is the IR volts drop and CF is determined as follows, from the similar triangles $D\,B\,C$ and $B\,C\,F$, Fig. 3,—

$$\frac{DC}{BC} = \frac{BC}{CF}$$

or

$$CF = \frac{(BC)^2}{DC}\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

From Fig. 3 it is apparent that DC is approximately equal to $2\,E_2$, since the relative values of AC and E_2 are something like 5 to 100. Therefore, since BC is equal to IX,—

$$CF = \frac{(IX)^2}{2\,E_2}$$

Equation (8) may now be put into the form,—

$$\textit{Regulation} = \frac{IR + \frac{(IX)^2}{2\,E_2}}{E_2}$$

or

$$\textit{Percent Regulation} = \textit{Percent IR} + \frac{(\textit{Percent IX})^2}{200}\ldots\ldots\ldots(10)$$

With a load having a lagging power-factor, the various quantities have the relation shown in Fig. 4. By definition,—

$$Regulation = \frac{E_1 - E_2}{E_2} = \frac{AF}{E_2}$$
$$= \frac{IR\cos\theta + IX\sin\theta + HF}{E_2}$$

From Fig. 4,—

$$HF = \frac{(BH)^2}{2\,E_2}$$

This is a relation similar to the one shown by equation (9). But,—

$$BH = IX\cos\theta - IR\sin\theta$$

or

$$Regulation = \frac{IR\cos\theta + IX\sin\theta}{E_2} + 0.5\,\frac{(IX\cos\theta - IR\sin\theta)^2}{E_2}$$

or

$$\begin{matrix}Percent\\Regulation\end{matrix} = Percent\ IR\cos\theta + Percent\ IX\sin\theta + \frac{(Percent\ IX\cos\theta - Percent\ IR\sin\theta)^2}{200}$$

For ordinary use the last term of this expression may be omitted. Then,—

$$Percent\ Regulation = Percent\ IR\cos\theta + Percent\ Ix\sin\theta \ldots (11)$$

With a load having a leading power-factor, the conditions are shown by Fig. 5. By definition,—

$$Regulation = \frac{E_1 - E_2}{E_2} = \frac{AF}{E_2}$$
$$= \frac{IR\cos\theta - IX\sin\theta + HF}{2\,E_2}$$

From Fig. 5,—

$$HF = \frac{(BH)^2}{2\,E_2}$$

This is a relation similar to the one shown by equation (9). But,—

$$BH = IX\cos\theta + IR\sin\theta$$

Hence,—

$$Regulation = \frac{IR\cos\theta - IX\sin\theta}{E_2} + 0.5\,\frac{(IX\cos\theta + IR\sin\theta)^2}{E_2}$$

or

$$\begin{matrix}Percent\\Regulation\end{matrix} = Percent\ IR\cos\theta - Percent\ IX\sin\theta + \frac{(Percent\ IX\cos\theta + Percent\ IR\sin\theta)^2}{200}$$

For ordinary use the last term of this expression may be omitted without error, then,—

$$Percent\ Regulation = Percent\ IR\cos\theta - Percent\ IX\sin\theta \ldots (12)$$

Example:— What is the percent regulation with a 100 percent power-factor load, of a five k.v.a. transformer which has a copper loss of 85 watts and an impedance of three percent?

If the transformer has an impedance of three percent and a resistance drop of 1.7 percent, the reactance drop is $3^2—1.7^2$ or 2.47 percent. Then, the regulation is, from equation (10),—

$$Percent\ Regulation = 1.7 + \frac{(2.47)^2}{200} = 1.73$$

The regulation of the same transformer with an 80 percent lagging power-factor load is, from equation (11),—

Percent Regulation $= 1.7 \times 0.8 + 2.47 \times 0.6 = 2.84$.

The regulation with a load having a leading power-factor of 90 percent is, from equation (12),—

Percent Regulation $= 1.7 \times 0.9 - 2.47 \times 0.44 = 0.44$.

With a load having a leading power-factor load of 80 percent, the regulation would be negative. That is, the voltage delivered at full load would be greater than the no-load voltage.

The Suppression of Arcs due to Accidental Grounds

M. H. Collbohm

SERVICE disturbances or interruptions in transmission systems are, in most cases, occasioned by grounds or short-circuits on the power line through outside influences, such as lightning, sleet, or wind. Effective means for eliminating such causes cannot, therefore, be provided within the system itself and relief can only be sought in suppressing their bad effects upon the system. Aside from the installation of ground wires above the power line and arcing horns for insulator protection, no means can be provided on the line itself to eliminate such disturbing effects immediately at the place of their first appearance on the system. For this reason, the disturbances must be permitted to travel along the line and to reach the station, where suitable devices for rendering them harmless can be installed conveniently and to good effect. Grounds can be taken care of by special apparatus within the stations without service interruption, while short-circuits usually interrupt the service on the affected line by the automatic opening of switches or, if they do not operate, by the throwing out of step of the synchronous machines in the system, due to excessive voltage drop.

Different kinds of equipment are in use for the elimination of ground trouble, depending upon whether the system operates with the neutral point isolated, dead-grounded, or grounded through a resistance.

In an Isolated System, use is made of the unbalanced electrostatic condition produced by a ground to operate a relay, which in turn dead-grounds the affected phase through an oil switch. This short-circuits the accidental ground and extinguishes any arc for lack of voltage to maintain it. By opening the oil switch immediately, normal conditions are again established unless the accidental ground is such as to re-establish the arc to ground on reapplication of normal voltage. This grounding equipment, called the arc suppressor,* is usually so adjusted as to close and open the grounding oil switch automatically several times in case of a persistent ground and finally remain closed if the ground cannot be removed thereby.

In a System with the Neutral Dead-Grounded, an accidental ground on any phase constitutes a short-circuit and either opens the circuit breaker or reduces the voltage of the system, thereby causing the synchronous apparatus to fall out of step. This results in an interruption of service every time a ground occurs and means can only be provided to shorten the period of interruption and to make the effect of the short-circuit upon the system less severe. To accomplish this, an equipment is

*"Protection of Electric Transmission Lines" by E. E. F. Creighton in *Trans. A.I.E.E.*, 1911, p. 257.

provided** consisting of a face plate with a number of contacts and a motor operated contact arm traveling over these contacts. The connections from these contact points to the apparatus and the sequence of operation are such that in case of a ground the resulting short-circuit current, through the action of an overload relay, causes the motor driven contact arm to travel slowly over the face plate contacts, thereby causing the following operations to be performed in the order given:—

1—The generator field switch is tripped open, thereby reducing the generator voltage practically to zero and extinguishing the accidental arc to ground.

2—The generator field switch is again closed permitting the generator voltage to build up again to normal.

If the arc to ground starts again on re-application of voltage, the cycle is repeated several times, and if the arc still persists, service will have to be interrupted until the trouble is removed or isolated. This method takes care of troubles obtaining on the system as a whole. For local distribution feeders and possible certain transmission lines a system is provided that, on occurence of overloads due to grounds, automatically interrupts the circuit for a very brief interval, immediately reclosing the circuit-breaker and limiting this cycle of operation to a definite number so that the feeder is automatically disconnected if permanently disabled.

The service-restoring system is applicable to both grounded and ungrounded circuits, in the latter case caring also for short-circuits.

In a System Grounded through a Resistance, an accidental ground does not produce a short-circuit but merely constitutes an additional single-phase load, held within convenient limits by the resistance of the ground resistor between transformer neutral and ground. The value of the resistor connected in the neutral circuit may vary from that required to automatically trip the feeder circuit-breaker under grounded conditions to the relatively high value sufficient to give indications on the station instruments. This latter value is the one used in the scheme discussed below.

For this system one method of providing for grounded circuit conditions is to install in a three-phase system independent oil switches connected between each of the three high-tension bus-bars and ground. A current transformer in the ground rheostat lead indicates the presence of a ground through the sounding of an alarm bell and the lighting up of a signal lamp. To remove an accidental ground, it is only necessary to ascertain from the line ammeters which phase is grounded and then close the oil switch connecting this phase to ground, thereby grounding the affected line conductor and extinguishing the accidental arc. By opening this grounding oil switch immediately, normal conditions are again established without having caused a service interruption. If the accidental ground persists, the grounding oil switch will be kept closed and the rheostat switch open until the affected feeder can be isolated. The system described herein involves manual operation of the circuit breakers. Similar methods providing automatic operation of the short-circuiting or by-passing device are also in use.

**"The Restoration of Service after a Necessary Interruption" by F. E. Ricketts, in *Trans. A. I. E. E.*, 1916, p. 635.

As the relative merits of the various methods depend upon their operating characteristics and their effect upon the system, it may be of interest to point out the distinguishing features of these equipments and their influence upon service.

POTENTIAL STRESSES

Due to the fact that the grounded system has metallic connection to ground, no slow accumulation of static potential is possible as any such potential is drained off by the ground connection as soon as formed. This cannot be accomplished in the ungrounded system, as the arc suppressor, if electrostatically controlled, operates only if the electrostatic balance of the circuit is materially disturbed, which would not obtain in this case, and as there is no other connection to ground to drain off the static potential. There exists, therefore, in the ungrounded system the possibility of potential accumulation which is absent in the grounded system, and for this reason the insulation resistance of the entire plant must be higher in the ungrounded system in order to obtain the same factor of safety. In making this statement, it is recognized that the arresters will discharge any potential above ground over that for which they are set, which would seem to bring both the grounded and ungrounded systems on a par in respect to danger from excessive potential stresses. There exists, however, a decided difference in that any excess potential stress in the grounded system is only of momentary duration while the potential accumulation in the ungrounded system may produce stresses lasting a considerable time and which may become dangerous through the fact that the resistance of the insulating material against puncture decreases with the time of application of the electrostatic stress.

Aside from the stresses produced by slow accumulation of static there also exists the danger from excessive voltage produced by resonance under oscillating ground conditions. Although the time elapsing between the appearance of the oscillating ground and the moment the arc suppressor has completed its operation may be short, it may yet be sufficient, if circuit conditions are favorable for resonance, to break down the insulation at some point in the system. This danger becomes more important if the arc suppressor is designed to close and open the ground connection automatically several times in succession which would throw repeatedly severe shocks upon the system and might produce a breakdown thereby. The danger from this cause is entirely eliminated in the grounded system, where a ground cannot become oscillatory on account of the dynamic power which passes over the arc and furnishes the necessary energy to maintain it.

MECHANICAL STRESSES

As pointed out before, every accidental ground in a dead-grounded system constitutes a short-circuit on the affected phase with a resulting heavy rush of current. This is a condition producing extremely heavy mechani-

cal stresses within the generators and transformers which is further aggravated by the fact that the short-circuit is usually permitted to exist for at least two seconds before the protective equipment is allowed to operate, in order to permit any grounded feeder of minor importance to trip off during this interval and thereby clear the rest of the system. These heavy mechanical stresses constitute a grave danger to the apparatus. They result in rapid deterioration and, according to experience, will in time cause a breakdown. This dangerous condition exists only remotely in the isolated system where heavy current surges may become possible through resonance, but is entirely absent in the system protected by a ground rheostat.

RELIABILITY OF OPERATION

As stated, there is an element of danger in the ungrounded system due to the time required for the arc suppressor to perform after the oscillatory ground has come into existence, and especially so if the arc suppressor is set for repeated successive action. It is, therefore, imperative that the arc suppressor be absolutely dependable at all times and under all conditions, and even then, the danger cannot be eliminated.

Although the protective equipment used in the dead-grounded system adapts itself to more rugged construction, it is yet more elaborate than that used with the ground rheostat, and therefore, does not possess quite as high a degree of reliability. The main objection however, lies in the danger to the station apparatus through the heavy mechanical stresses set up by the ground currents, which decreases the safety factor of the system as a whole.

Entirely different conditions obtain in the grounded system using the metallic ground rheosat for indicating accidental grounds. In this case, a failure of the grounding equipment to operate means no danger to the system for the reason that no oscillating arc and, therefore, no dangerous potentials, can exist nor can there be any severe mechanical stresses. The essential difference in the various systems in this regard is, therefore, as follows:—

1—In the system with neutral isolated, a ground becomes oscillatory and, therefore, dangerous and requires proper and immediate action to remove this danger.

2—In the system with the neutral dead-grounded, a ground becomes a short-circuit and sets up heavy mechanical stresses in the station apparatus, thereby seriously endangering the equipment.

3—In the system using the ground rheostat a ground does not introduce danger and failure of the grounding equipment to perform properly is of no immediate consequence.

The reliability of a grounding rheostat in high-voltage work can be increased by dividing the rheostat into a number of sections in series, each placed upon high-voltage insulators and preferably located in separate compartments. This reduces the voltage drop across each section and thereby renders the apparatus thoroughly reliable as shown by many years of practical experience.

ATTENDANCE REQUIRED

On account of the danger that lies in the time required by the arc suppressor to operate, this time must be made as short as possible and demands, therefore, an automatic operation.

The ground rheostat with grounding switch equipment does not require automatic operation. The only relay which is required serves to ring an alarm bell and light a signal lamp and is of very simple construction needing no special or constant care.

DETECTION OF FAULTY LINE

It is very important to ascertain on which feeder the trouble exists in order to be able to isolate it for removing the influence of its fault upon the rest of the system, and to begin repair work on the damaged feeder at the earliest possible moment. Neither the arc suppressor nor the equipment used in the dead-grounded and low-resistance grounded systems lends itself readily to the detection of the damaged line without disconnecting the circuit for the reason that the time for the observation of the swichboard instruments before the protective equipment begins to operate is very short. In most cases the operator will, therefore, not be in a position to detect the damaged line from instrument readings. Furthermore, as an arcing ground generally affects the whole system, instrument indications are apt to be indefinite and, therefore, unreliable. Compared with the positive and very distinct readings of the line ammeters in the system operating with a grounding rheostat where sufficient time can be allowed for a convenient reading of the instruments, the superiority of the grounding rheostat in this respect is evident.

ADVANTAGE OF GROUND RHEOSTAT FOR LINE TESTING AND EMERGENCY CONSTRUCTION

An additional benefit may be obtained from a ground rheostat in testing out a new line or one having been repaired. Usually service does not permit the gradual building up of voltage on a new or repaired line and even if this were feasible, the possible sudden appearance of an accidental short-circuit near full voltage would throw a very severe strain upon the system, with the likelihood of damage and service interruption. This danger can be avoided by the use of the ground rheostat by connecting up each line conductor separately in succession through disconnecting switches without lowering the voltage. A ground will then be detected and located among the various conductors immediately and without disturbance. Frequently a line is projected for a double circuit with the idea of adding the duplicate line at some future time when the increase of load or other conditions should make this necessary. At such times, the ground rheostat would be of considerable advantage by preventing trouble from accidental contact of the new line wire with the existing power line in the course of stringing, particularly at times of high wind. Such accidental contact can hardly be avoided, but through the use of a ground rheostat, and by keeping the new line wires thoroughly grounded, no harm can result either to the line men or to the service. This was borne out in practice several years ago when one of the transmission companies in the Middle West added a duplicate circuit

on its tower line without service interruption, in spite of more than a hundred grounds caused by contact of the new line through high winds.

COMPARATIVE COST

On account of the automatic feature required by the arcing ground suppressor, the equipment is rather elaborate as compared with that of the grounding rheostat where manual operation is feasible and even preferable. For this reason, the cost of a complete equipment for an arcing ground suppressor is several times that of a grounding rheostat. The cost of the protective equipment used in the dead-grounded system is also likely to be greater, particularly if more than one generating station is involved.

RESULTS FROM PRACTICAL OPERATION

The results of several years experience with the ground rheostat by different power companies has fully demonstrated the serviceability and reliability of this equipment and its beneficial effect upon continuity of service. This has been particularly evident with the companies who have installed the ground rheostat after having operated without one. The rheostats used by these companies had a rating of 15 amperes, 38 000 and 25 000 volts respectively for three or five minutes, which has proven to be ample to prevent oscillatory arcing and still offer the advantage of having the arcs over the insulators occasionally extinguish merely by the action of the wind alone, before the grounding oil circuit breakers at the station operate.

Mechanical Problems in the Design of Electric Locomotives

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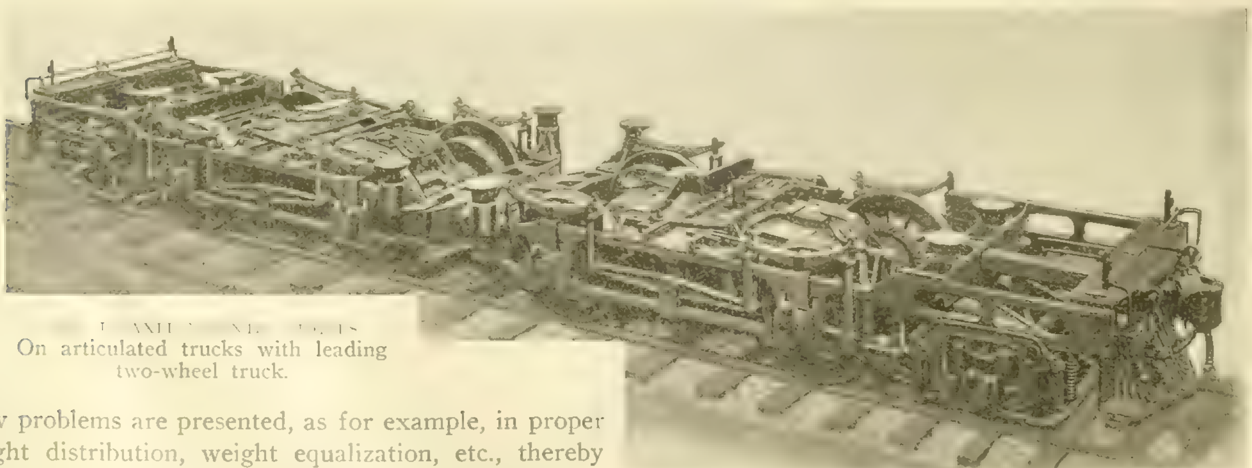
Westinghouse Electric & Mfg. Company

THE SERVICE requirements for steam and electric locomotives are similar;— both must deliver a specified draw-bar pull at a specified rate of speed. In doing this, the problem is to convert some other form of energy to mechanical energy and to transmit it to the driving wheels. Many broad structural problems are thus presented which are common to both designs. In the electric locomotive, electrical instead of thermal energy is utilized, and on account of this difference, many particular problems become quite dissimilar.



On articulated trucks with leading two-wheel truck.

New problems are presented, as for example, in proper weight distribution, weight equalization, etc., thereby rendering it necessary to analyze the entire locomotive. Analogies may be drawn from the steam locomotive and much benefit taken from experience gained in their manufacture and operation, but design features blindly copied from the best steam locomotive practice may utterly fail when applied on an electric locomotive. The limitations imposed upon the draw-bar pull and speed of electric locomotives are largely mechanical. Hence any improvements in mechanical design will tend toward increased rating, greater reliability and increased economy.

The problems involved in the mechanical design of the main structures and of the rotating parts may be grouped under three main headings:—

1—Problems relative to tracking qualities.
2—Problems relative to the transmission of power from the motors to the rails.
3—Problems relative to the design of the motors themselves.

These three general problems are interdependent. The tracking qualities of the driving trucks largely depend upon the position and weight of the motors. The type of drive is also governed by the location of the motors and particularly by their position relative to the driving wheels. On the other hand, the size, number, and speed of the motors are governed not only by electrical considerations but also by the type of drive and by the way they are mounted.

The position of the center of gravity in the vertical plane is very important in the determination of the tracking qualities, that is, the manner of running on tangent track, taking curves, and going over the track irregularities, such as switch frogs etc. In some cases, a low center of gravity makes a slightly cheaper locomo-

tive, but a relatively high center of gravity has the advantage of better running qualities. In these particular instances, it may be a question of track vs. locomotive maintenance.

Closely associated with the problem of the position of the center of gravity relative to the rails, is that of the position of the center of gravity in the horizontal plane. An important factor in this connection is the disposition of masses with reference to center pin. Excessive stresses in the rails and the flanges of the drivers should be avoided under all operating conditions. With a high moment of inertia about the center pin, irregularities in the track may cause the truck to swing from side to side, resulting in excessive thrust against the rails and wheel flanges, thereby causing track distortion and possible derailment. This is most likely to occur at high speeds.

The distribution of weight has an important bearing upon this phenomenon; the position of the motors and even the type of drive may be governed by this consideration. The tractive effort which a driving wheel

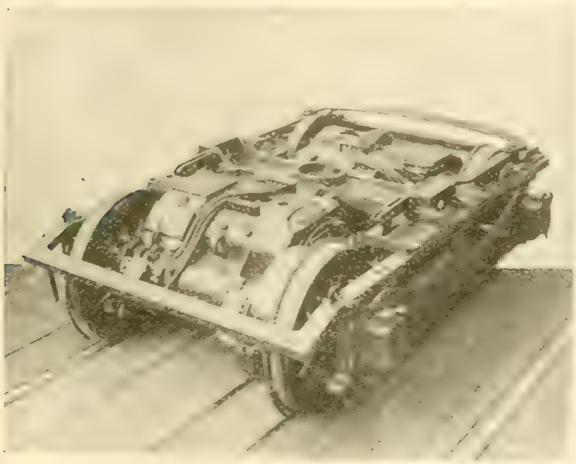


FIG. 2—AXLE-MOUNTED MOTORS ON SWIVEL TRUCK

is able to exert without slipping, other things being equal, is proportional to the weight on that driver. The functions of the leading and trailing trucks are to help in supporting the total weight of the locomotive, to iron down the track for the driving wheels and to guide them into curves. The tractive effort required per pair of drivers and the necessary amount of ironing and guiding effect determine the weight distribution between axles. Since the weight on any pair of drivers is limited by the permissible rail loading, the tractive effort per axle is limited.

Another limit to the tractive effort is that imposed by weight transfer. Tractive effort is exerted by the drivers at the rails, and draw-bar pull at the coupler, about thirty-four inches above the rails. These two forces, being equal and opposite, produce a couple tending to tip up the truck at the front end. This increases the weight on the rear drivers and decreases the weight on the front drivers. In the case of axle-mounted or quill-mounted motors, the front drivers will slip at a lower locomotive draw-bar pull, than where the drivers are connected by side rods, thereby reducing the locomotive tractive effort.

A heavy dead or non-spring-borne weight per axle may produce undue stresses in the track structure. This dead weight consists of the weight of the drivers, axles, and in the case of axle-mounted motors, the

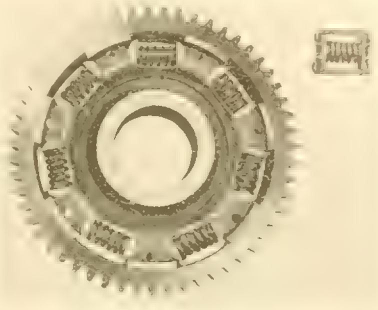


FIG. 3—FLEXIBLE GEAR

weight of the axle bearings, gear and gear case, and approximately five-eighths of the motor weight. It is evident, therefore, that an inherent limitation is placed upon the size of axle-mounted motors. The side frames of the trucks and other details must be designed with reference to all the above considerations and must also be capable of withstanding stresses due to coupling, train surges, and abnormal conditions such as derailments. Most high-powered electric locomotives have articulated trucks. The articulated couplings serve to transmit the draw-bar pull from truck to truck, and yet permit the trucks to take curves and go over irregularities in the track unhampered.

TRANSMISSION OF POWER

The second group of problems relative to the transmission of power from the motors to the rails has received a great deal of attention. Solid gear drive with axle-suspended motors was first developed and is used on street and interurban cars, and on some locomotives. Rapid strides have since been made in the design of gears for heavy service. One of the most important of these was the development of flexible gears which have proven their worth under heavy operating conditions

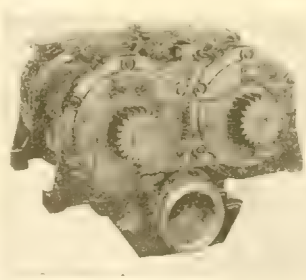


FIG. 4—TWIN-TYPE, SINGLE-PHASE, SERIES MOTOR

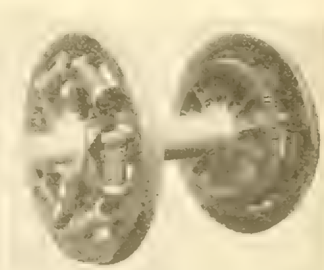


FIG. 5—WHEELS AND AXLE WITH QUILL AND HELICAL SPRINGS

and will doubtless be used more and more extensively on heavy interurban cars and locomotives. The principal advantages of this type of gear are the elimination of shocks due to sudden starting and to track irregularities, and the even distribution of load where double end gears are used.

To avoid the dead weight inherent in axle mountings, preferably large motors are mounted on the trucks, introducing a spring cushion between their weight and the rail. This causes complication in the driving system. There must be a positive connection between the motors and the driving wheels to transmit the power, and at the same time the motors must, to a certain extent, be free to move vertically with reference to the driving axles.

The quill type of drive is one solution of this problem. The motors are mounted on the trucks and geared to a hollow shaft, known as the quill, which is carried in a bearing rigidly connected to the motor frame. The driving axle passes through the quill, which by means of cast steel spiders on each end engages the spokes of the drivers through tangential helical springs. Vertical motion is thus permitted between the motors and the driving axles. Flexible gears are often used with quill drive to equalize the load when gears are used on both ends of the motor.

A condition of resonance is possible in any type of drive where two bodies have relatively high moments of inertia and are connected by a more or less elastic medium. The relation between the natural period of the springs used in flexible gears or quills, and the natural period of oscillation of the rotors and drivers must be such that resonance does not occur throughout the range of speed of the locomotive.

Side rods are also used to transmit the torque from truck-mounted motors to the drivers. With this type of drive the motors may be mounted higher on the trucks, thus raising the center of gravity and bettering the tracking qualities. In the application of this type of drive to electric locomotives in this country, a jack shaft is used. The motors are either directly connected to the jack shaft by side rods, or geared to it by solid or flexible gears. A great many different types of side-rod drives have been developed, especially in Europe, with varying degrees of success.

The problem of designing side rods for electric locomotives is more involved than for steam locomotives. In the latter case, the static stresses may be determined from the position of the crank at any instant and from the indicator diagram. The systems of side-rod drive on each side of the locomotive are independent and have relatively low inertia. In the case of the electric locomotive, the two systems are connected by cranks and shafts at each end. A calculation of the static stresses must take into account the flexure of the rods, the crank-pin bearing and journal clearances and the probable accuracy of workmanship in locating crank pins. The motion of the rods in space, and hence the stresses due to whipping at high speeds are different. In the electric locomotive, the rods connect two high inertia bodies, the drivers and the rotors, and as the rods are more or less elastic, unless proper precaution are taken resonant conditions may occur. The high moment of inertia of the rotors imposes severe stresses on the driving rods when the locomotive is stopped suddenly.

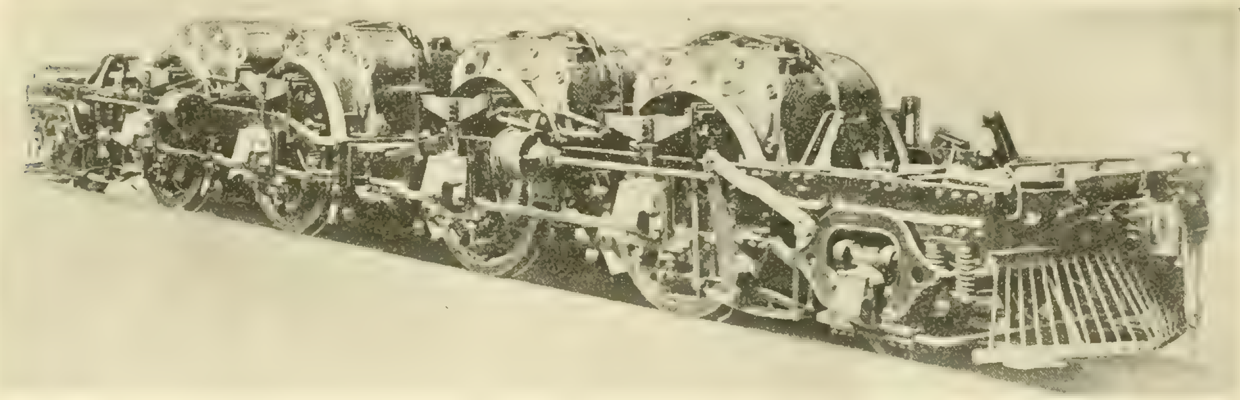


FIG. 6—TWIN MOTORS AND QUILL DRIVE ON ARTICULATED TRUCKS
With leading two-wheel trucks.

DESIGN OF MOTORS

Most of the mechanical problems relative to the design of the motors are closely associated with the electrical features. One of the most important of these is the design of the bearings. Since the over-all length of the motors is limited by the distance between wheel flanges or between cranks, whatever space is taken by the bearings reduces the motor length and hence the output. The most economical compromise is reached when enough length is conceded to the bearings to permit them to transmit the maximum power the motor can economically deliver with the resulting length of core.

Regenerative braking introduces another problem. The bearing pressure is reversed without reversing the direction of rotation of the motor, and trouble may be experienced in maintaining a proper oil film in ordinary bearings. Roller bearings and ball bearings are being introduced in electric traction, but experience with them is so limited that they are seldom applied to any but small motors. There are numerous other bearing considerations on electric locomotives, such as journal and crank-pin bearings, and the bearings on the auxiliary apparatus.

The main motor shafts are subject to stresses due to the motor torque and the weight of the rotors. They must be capable of resisting strains due to sudden stopping or severe over loads. The permissable amount of shaft flexure is limited. This deflection is due to a com-

bination of the rotor weight, unbalanced magnetic pull and, in the case of rod-drive locomotives, to crank-pin pressure.

When the main motors are directly connected to the drivers by means of side rods alone, since there are no gears, any yield, if desired, must be introduced between the motor rotor and the crank on the motor shaft. This may be accomplished by springs or by a friction clutch adjusted to slip at a high value of motor torque, between the rotor spider and the motor shaft.

FIG. 7—DIRECT DRIVE ON ARTICULATED TRUCKS
With leading four-wheel trucks.

All railway apparatus may be subjected to very severe vibration. Every nut and screw on the locomotive must be effectively locked. Even rivets of insufficient cross-section or incorrectly set, will sometimes allow a slight relative movement between parts, ultimately resulting in excessive wear or breakage.

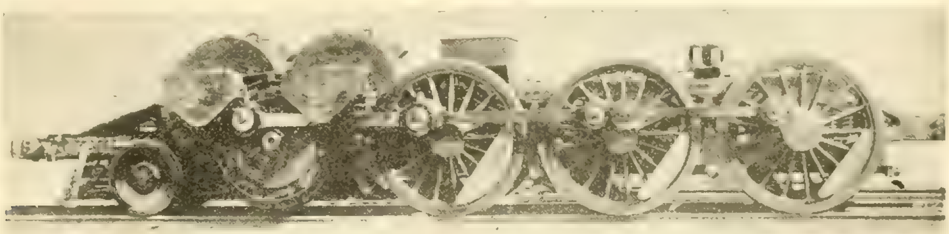


FIG. 8—GEAR AND SIDE-ROD DRIVE ON ARTICULATED TRUCKS
With leading two-wheel truck.

Some parts of the electrical apparatus are subjected to very heavy stresses due to occasional short-circuits. Braces are designed to withstand these stresses and at the same time, to guard against movement due to vibration and sudden mechanical shocks due to other causes.

One of the important mechanical considerations in connection with the electrical apparatus is that of the design of castings. These castings must fulfill all electrical and mechanical requirements placed upon them and yet be so shaped that the cost of patterns and moulds will not be excessive. Sometimes a slight change in a casting that does not affect the mechanical or electrical design in the least, will make quite a substantial reduction in its cost.

Another important consideration in the design of the motors and much of the auxiliary apparatus is that of ventilation. Forced ventilation is becoming more generally used and it is probable that practically all large locomotives will use this system of cooling. A new design requires detailed study to predetermine the amount of air necessary to dissipate the losses and the pressures necessary to drive the required amount of air through the apparatus. The two goals are to get maximum cooling with a minimum of air, and a maximum of air with a minimum of power from the blower motor.

Some of the more important mechanical considerations encountered in the design of electric locomotives have been outlined. This is an important field for development. At present, for a given rail loading and speed there seems to be a fairly definite limit to the draw-bar pull per foot length of locomotive. This maximum draw-bar pull is usually demanded in the case of freight locomotives where the most advantageous speed is between fifteen and twenty miles per hour. The problem then is to increase the draw-bar pull without making an abnormally long locomotive. Improvements in materials and higher permissible stresses as well as improvements in mechanical design not only in the locomotive but also in the track structure will do much towards answering the requirements of the railroads for more and more powerful locomotives.

Industrial Controllers-XIII

Steel Mill Floor Controllers for Auxiliary Drives

H. D. JAMES and E. S. LAMMERS, JR.

FEW applications of electric motors and controllers involve more severe service than floor controllers used in steel mills. The motors are started and stopped very frequently, usually under heavy loads, and large starting currents are used to obtain quick acceleration. The control apparatus must be rugged and should have a minimum number of interlocks and other auxiliary contacts. Provision should be made for repairs and renewals in the minmum length of time. It is very desirable to have the parts subject to wear or accident removable from the front of the control board, and one man should be able to handle this work without assistance, except where the parts are very heavy.

Floor controllers group themselves into four general classes for reversible service. Where a non-reversing controller is used, it follows the same grouping except that one set of reverse switches is omitted:—

AA—Plugging on the reverse, without speed control; acceleration by lockout switches.

BB—Plugging on the reverse with speed control; acceleration by shunt switches with current limit relays.

CC—Dynamic brake without speed control. Lockout switches are used for acceleration.

DD—Dynamic brake with speed control; the acceleration is by shunt switches with current limit relays.

Schematic diagrams showing the reversible controllers are illustrated in Figs. 1 to 4. All of these controllers consist essentially of two line switches, one for forward and the other for the reverse direction of operation. The controllers illustrated use a mechanical interlock so that both forward and reverse switches cannot be closed at the same time. These switches for controllers *CC* and *DD* are provided with back contacts; when both direction switches are opened, the two back contacts complete the dynamic brake circuit. The coils maintaining pressure on these back contacts are in series with the contacts and hold them closed as long as current is flowing through this circuit. This arrangement also prevents the motor from being operated in the reverse direction as long as the dynamic brake current lasts. The single-pole contactor with blowout, which is used for opening the negative side of the line is shown in the top row, Figs. 5 and 6. At the bottom of the panels are two contactors for short-circuiting the starting resistor. In Fig. 5, these contactors are wound with series coils and operated on the lockout principle. In Fig. 6, the contactors have shunt coils and are controlled by current limit relays. One of these relays is shown mounted underneath the resistor switch. The other relay is mounted under the direction switch.

These panels have a two-pole overload relay and a low-voltage protective relay. The overload relay is provided with two coils, each having a dashpot time-limit device. The plungers actuated by either of these coils engage a single switch member, which opens the potential relay circuit in case of overload. The use of the two-pole overload relay and the negative line switch gives maximum protection against grounds, which are apt to occur in applications of this kind. In the *off* position, the controller disconnects the armature from the line. If no negative line switch is used, one end of the series field is connected to the line, so that it is not safe to work on the motor without opening the knife switch.

In the upper right hand corner of the panel is a two-pole, single-throw knife switch for disconnecting the feed wires from the panel. A similar two-pole single-throw knife switch and fuses are located underneath the overload relay for the control wiring. The

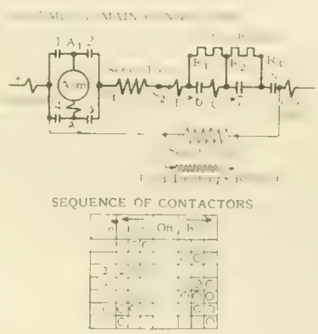


FIG. 1.

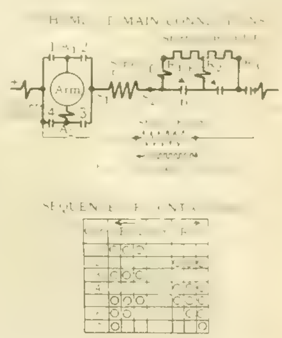


FIG. 2.

FIG. 1—SCHEME OF MAIN CONNECTIONS FOR FORM *AA* CONTROLLER

Acceleration is by means of series lockout magnet switches* 6 and 7, which are operated by series coils *B* and *C* respectively. The motor is connected for forward or reverse operation by closing contactors 1 and 3 or 2 and 4 respectively. With this form of controller, acceleration is entirely automatic.

FIG. 2—SCHEME OF MAIN CONNECTIONS FOR FORM *BB* CONTROLLER

The operation of this form of controller is the same as the *AA*, except that the automatic acceleration is by means of series relays,** the switches being closed by shunt coils which are in series both with the master controller and with the series relay contacts. With this scheme, acceleration is automatic up to the position at which the master controller is set. Coils *D* and *E* are the series coils of the relays which control the operation of switches 6 and 7 respectively.

main line knife switch, as well as the smaller knife switch and fuses, can be provided with sheet metal covers to protect the operator from accidental flashes if the switch is opened under load. The large knife switch is provided with an attachment for a padlock so that the switch can be locked in the open position when repair-work is going on. By opening the main knife switch and closing the control knife switch, the control circuits can be tested out and the operation of the contactors observed, to see that the equipment is in working order, before power is applied to the main contacts.

Usually these control panels are protected by grill work or in some other manner, or they are mounted in a gallery, which is accessible only to authorized persons.

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*See the JOURNAL for March '17, Fig. 4, p. 104.

**See the JOURNAL for March '17, Fig. 3, p. 103.

In some states these precautions are required by law. In the main, however, the steel mill companies recognize the importance of such a safety provisions and use them whether required by law or not.

The reason for dividing the controllers into four classes can best be understood by giving some of the applications for each class of control. These applications are not complete and are intended only to illustrate the use of each class of control.

Class AA Controllers are applied to all of the main and auxiliary tables requiring one speed only. These tables usually consist of a series of rollers; the steel rests on the rollers and is moved forward or back by revolving the rollers.

Class BB Controllers are used for similar application where two or more speeds of operation are required. A two high reversing mill is outlined in Fig. 7. The circles *A* and *B* represent the main rolls for fabricating the steel. The horizontal row of circles represents the table rolls which are driven by electric motors

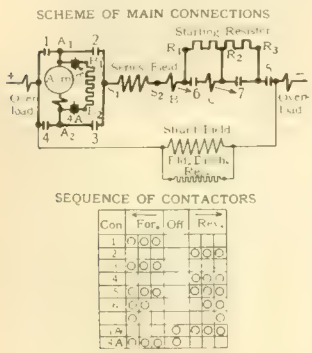

FIG. 3.

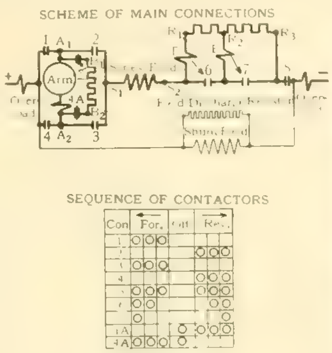

FIG. 4.

FIG. 3 SCHEME OF MAIN CONNECTIONS FOR FORM *CC* CONTROLLER

This controller is the same as that shown in Fig. 1, except that it is arranged for dynamic braking in the off position of the contactors. The brake resistor B_1 B_2 is connected across the motor armature through contacts 1*A* and 4*A*. These contacts are on the bottom of switches 1 and 4 so that both sets of reverse switches must be open before dynamic braking is obtained. The current in passing through contacts 1*A* and 4*A* energizes magnets which press these contacts firmly together as long as the dynamic brake current is flowing, and effectually prevent the reversal of the motor as long as its speed is sufficient to send current through these coils.

FIG. 4 SCHEME OF MAIN CONNECTIONS FOR FORM *DD* CONTROLLER

This controller is the same as that shown in Fig. 2, except that dynamic braking is provided in the off position in the same manner as shown in Fig. 3.

through suitable gearing. The steel billet is moved up to the main rolls in the direction shown, by revolving the table rolls. After the billet has entered the main rolls, it is carried through by the action of these rolls and is delivered to the table rolls on the left hand side. By reversing the direction of the main rolls and table rolls on both sides, the billet is fed back through the main rolls, the process being repeated until the desired reduction is secured. Each of these operations is known as a "pass". After the billet has been rolled to a given size by one set of main rolls, it is often passed to other rolls, or the same set of rolls may have several different shaped grooves, so that the billet can be moved sideways and made to enter these grooves during successive passes. The movement of the billet sideways is controlled by the side guards, which consist of horizontal bars, which are moved across the table rolls for placing the billet in the proper position. If it is desired to turn the billet over, manipulator fingers are used. These fingers are attached to the side guards and extend underneath the billet between the table rolls. These manipulator fingers are connected so that they can be raised and lowered. This movement, when properly directed, serves to turn the billet over. The distance between the main rolls *A* and *B* is adjusted by means of an electric motor, geared to screws which act against a constant hydraulic pressure tending to raise the top roll. If the screws are raised, the hydraulic pressure will cause the top roll to follow. If it is desired to lower the top roll, it is necessary for the motor to drive the screws down with sufficient force to overcome the hydraulic pressure. This is known as the "screw-down" motion. It can be readily seen that the adjustment between these rolls must be very exact, and therefore it is important that the control of the screw-down motor provide for stopping this motor with practically no drift.

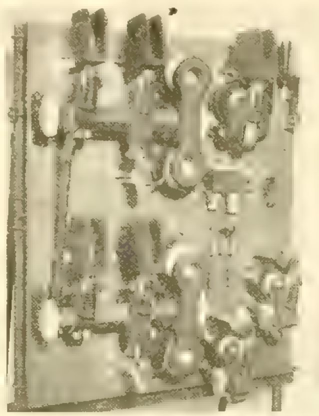

FIG. 5

FIG. 6

FIG. 5 FORM *CC* CONTROLLER

This controller corresponds to the diagram shown in Fig. 3. The reverse switches have two top contacts, 1 and 3 for forward operation with back contact 1*A*, and 2 and 4 for reverse operation with bottom contact 4*A*. These switches are mechanically interlocked by the rod at the left, to prevent both from closing at the same time. Contact 5 is shown in the upper right hand corner, and lockout accelerating switches 6 and 7 at the bottom of the panel. Both the reverse switches and the line contactor 5 are actuated by shunt coils not shown in the diagram. An over-load relay is located directly under switch 5 and two-pole knife switches are provided for disconnecting the main and control circuits from the line.

FIG. 6—FORM *DD* CONTROLLER

This controller corresponds to the diagram shown in Fig. 4. It is the same as Fig. 5, except that accelerating switches 6 and 7 are actuated by shunt coils which are controlled by the series relays, one of which is shown mounted underneath switch 6.

Class CC Controllers are applied to screw-down, lifting and tilting tables, manipulator fingers, and side guards.

Class DD Controllers are used for metal mixers and Bessemer converters, and are also used for the same applications as Class *CC* where speed control is desired. A three-high mill with tilting tables is shown in Fig. 8. The main rolls are illustrated by circles *A, B* and *C*. Roll *B* is an idler. The steel to be rolled in this form of mill is usually a plate and the mills used are usually called "plate mills." The red hot steel plate is passed alternately between rolls *A* and *B* from right to left and

back from left to right between rolls B and C. The screw-down motion adjusts the distance between rolls A and C, roll B being free so that when the pass is made between rolls A and B, roll B is forced against roll C. When the pass is in the opposite direction between B and C, roll B is pressed against A.

In order to pass the steel plate alternately between A and B and B and C, it is necessary to tilt the tables;

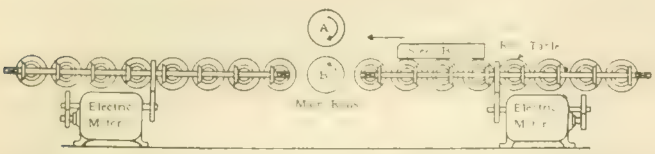

FIG. 7—TYPICAL APPLICATION OF ELECTRIC MOTORS TO REVERSING ROLL TABLES OF BLOOMING MILL

hence, the term "tilting table." The end of the table away from the rolls is hinged and the opposite end of the table is raised or lowered by means of an electric motor. These tables have two fixed positions, which are previously adjusted so that the motors are automatically stopped when the tables reach these positions. The tables are counter-weighted, as shown, in order to equalize the work done between raising and lowering. The masses moved, however, are great and as an accurate stop is required, it is necessary to provide a slowdown before the final stop. Fig. 9 illustrates the controller used for this purpose. When the table approaches either limit of travel, switches *7* and *8* are opened and switch *8-A* is closed. This inserts the starting resistance in series with the motor and also provides a shunt around the motor armature. These connections can be adjusted to give a positive slow speed, from which an accurate stop can be made. The problem is very similar to that of an elevator or skip hoist, which is moved up and down between fixed limits. In bringing tables to rest, switches *1-A* and *4-A* are closed at the same time that the line switches are opened, which provides a dynamic braking path of low resistance around the armature. In addition, the circuit through the mechanical braking magnet is opened so that the brake shoes set and assist in stopping the load, as well as hold it securely. The accurate placing of these tables at either limit of travel is facilitated by the

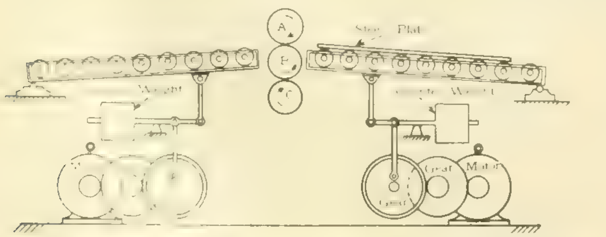

FIG. 8—TYPICAL APPLICATION OF MOTORS AND GEARS TO TILTING ROLL TABLE OF PLATE MILL

use of a crank motion. The stop is made when the crank is at either the top or bottom of the travel, so that a slight variation in the point of stopping makes little difference in the location of the table.

The controller switches are operated automatically by a stop motion switch, shown in Fig. 10, whose actuating shaft is connected to the mechanism. On the shaft is mounted a set of cams which open or close the limit switches at the proper time. The cams are adjustable, so that each switch can be set to open and close at the proper point in the travel. The use of cams gives a quick motion to these switches and enables an accurate setting to be obtained.

The motor is started by means of the master switch shown in Fig. 11. This master switch is also used in connection with the other controllers, previously described. The central position of the handle disconnects the motor from the line and resets the no-voltage switch in case the overload has opened it. The movement of the handle either side of the center operates the controller forward or reverse. One slow-speed point and one full-speed point are provided in each direction. Where the application requires more running notches, a different form of master switch is used.

A lifting table is very similar to a tilting table, except that the table is moved vertically up and down instead of having one end hinged and the other end raised and lowered. The results accomplished are the same, but a somewhat different mechanism is used. Usually the lifting table is confined to rolling operations which do not require a very long table.

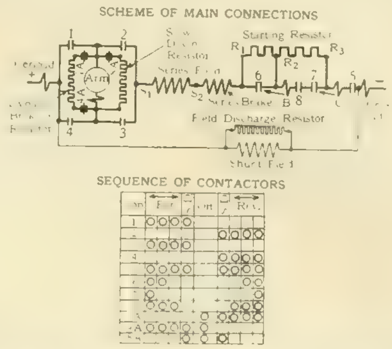

FIG. 9—MAIN CONNECTIONS OF CONTROLLER WITH ONE POINT SLOW-DOWN

This controller is the same as Fig. 3 with the addition of switch 8. When it is desired to slow down the motor, preparatory to stopping, the shunt coil of switch 8 is disconnected from the line by means of the limit-switch shown in Fig. 10. This, in turn, causes coil B to open 6 and therefore inserts all the starting resistance and closes a shunt around the armature through contact 8*A*, leaving the motor connected to the line with the starting resistor in series with, and the slow-down resistor shunted across the armature, providing a slow running motion.* The bottom contact of switch 8, marked 8*A*, has a series coil to retain the switch in the open position as long as current is flowing through contact 8*A*. If the line switches were open and the dynamic resistance omitted, some dynamic brake action would occur due to the resistor across the armature through contact 8*A*. This resistor, however, is of too large an ohmic value to give a quick stop, and it is, therefore, necessary to use the additional dynamic braking resistor to bring the motor quickly to a standstill.

Tests indicate that, on many applications, the best results are obtained with very few accelerating points. There are two ways of approaching this problem. Those who argue for a large number of accelerating points call attention to the fact that the current can be maintained at a higher level and thus furnish a larger average accelerating torque. The advocates of a small number of steps show that each switch requires a certain time in which to operate. Where the acceleration must take place in two or three seconds, too much time is con-

*See the JOURNAL for April '17, Fig. 4, p. 151.

sumed in the closing of these switches; also high current peaks must be used in any event.

In Fig. 12 are illustrated tests on a 100 horse-power, 230 volt, compound-wound direct-current motor

FIG. 10—CAM LIMIT SWITCH FOR GEAR OR SPROCKET CONNECTION

operating the main mill table for a 40 inch blooming mill. Three resistor switches were used but the tests showed that the action of the last resistor switch was too slow to be of material value. On closing the line switch, the first current peak is obtained. The second and third current peaks are caused by the first two resistor switches. The slope of the curve at each succeeding resistance point becomes steeper and steeper until it approaches a vertical line after the second resistor switch is operated. The result is that the motor has ap-

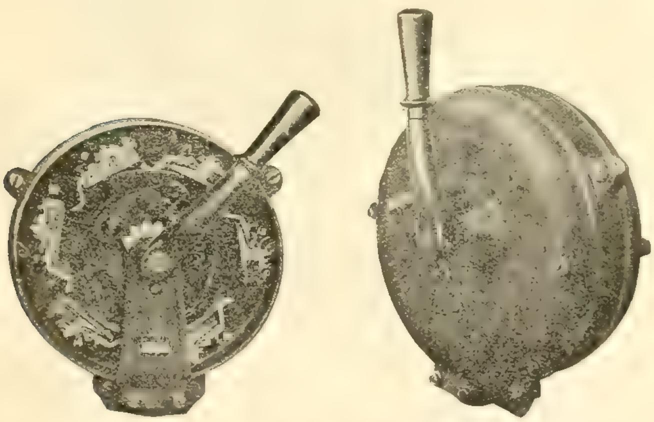

FIG. 11—TWO-POINT MASTER SWITCH

proximately reached full speed and the last resistor switch makes only a small bump in the current curve. Other tests* indicate that there is a reaction in the current curve, which normally tends to throw it below the calculated value of current, and then causes a secondary rise so that the wavy portion of the current curve, appearing after the second resistor switch is closed, is partly due to this effect, and still further eliminates the action of the last resistor switch. This particular application will give just as good service using only two switches for short-circuiting the resistor during acceleration. The current peaks had a maximum value of about twice full load, which is permissible for an application of this kind. The minimum value of current is a little in excess of the full-load value. This record shows an operation extending over 40 seconds and involves three starts and stops in each direction, or a total of six passes.

The above application is typical of steel mill requirements for auxiliary drive. The motor is usually operated for a very short period of time, during which the period of acceleration is a large part of the complete cycle. The size of the motor is determined from the power required to accelerate the masses moved. After the motor comes up to speed, the load drops off to a

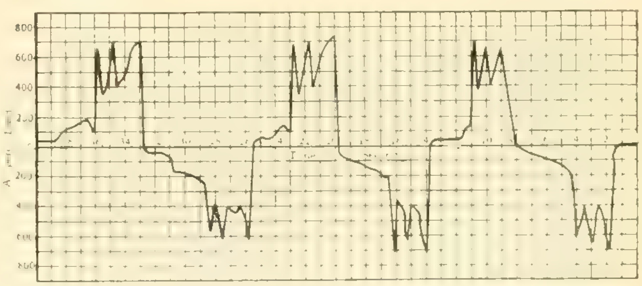

FIG. 12—LOAD CURVE OF 100 HP., 230 VOLT, COMPOUND-WOUND MOTOR OPERATING MAIN ROLL TABLE OF A 40 INCH BLOOMING MILL

very small value, as it is almost entirely friction. Motors for this service must be capable of withstanding severe mechanical shocks and must be designed to have small inertia for the torque delivered. The armatures are usually long and small in diameter, and the mechanical parts exceedingly rugged for the rating of the motor. Practice, has shown that motors of standard construction, which are suitable for machine tools and ordinary machine shop applications, will be racked to pieces in steel mill service. Motors have therefore been available for a number of years, known as the "steel mill type."

Every steel mill has machine tools, fans, pumps, and other applications, which differ in no material way from similar applications in ordinary machine shop practice. Standard motors and controllers are used for these applications. It is always desirable, however, to have the contacts and interlocking parts of these controllers interchangeable with those used for floor controllers connected to the auxiliary drive, in order to reduce the spare parts to a minimum.

*See the JOURNAL for Sept. 17, Figs. 11 and 12, p 353

Starting Rotary Converters

When Connected to Transformer Secondaries

F. D. Newbury and M. W. Smith

The starting of rotary converters from the direct-current end requires a larger starting current and the torque is not so good when the transformer secondaries are permanently connected to the slip rings, than when the alternating-current circuit is open. Difficulties in starting sometimes arise under such conditions, and hand starting may be necessary. These conditions are analyzed in the following article.

When there are no switches between the collector rings of a rotary converter and its transformer secondaries, the latter act as shunts to the converter armature, and divert a very considerable part of the starting current from the armature. This effect is greatest when the armature happens to stop in such a position that the direct-current brushes and the alternating-current collector ring taps are connected to the same coils, a condition which may exist with a two-phase or diametrically-connected six-phase unit, since both direct-current and alternating-current connections to the armature are spaced 180 electrical degrees. The shunting effect is a minimum when the tap coils have a maximum displacement from the coils connected to the direct-current brushes. In a two-phase armature this position of minimum shunting effect (and maximum starting torque) is 45 electrical degrees from the position of maximum shunting effect. This change from minimum to maximum torque occurs during a very small part of a revolution—in a converter with 14 poles it is one-fifty-sixth of a revolution or about six mechanical degrees. If the armature stops in the position

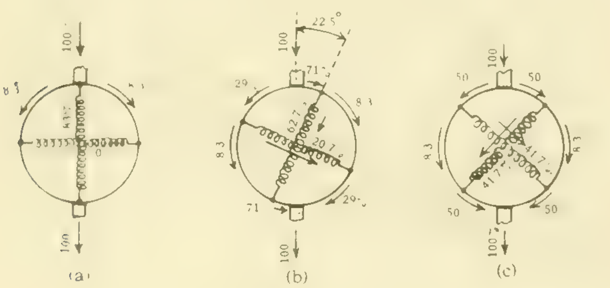

FIG. 1

of minimum torque, the torque can be doubled by turning the armature only two commutator bars. In such a case barring the armature by hand for a short distance may bring it to a position where it will have sufficient torque to overcome the initial starting friction.

The extent of the reduction in starting torque caused by the transformer secondaries is, of course, affected by the relative resistances of the armature and transformer. In a rotary converter, the armature resistance is high (due to the small effective current in the armature when operating as a converter) and may be as much as five times the resistance of a single secondary winding. Assuming this ratio and further that the starting current will be constant for the different positions of the armature (the resistance in the starting rheostat is very large, as compared with the converter and transformer, and will largely determine the current), the armature and transformer currents will be as shown in Fig. 1, (a), (b) and (c) for three positions of the armature. If it is assumed that the torque produced is proportional to the average current in the armature winding (this is only roughly correct, as the magnetic field varies in density to a considerable degree at different points in the air-gap), the torques in the different armature positions vary from 16.7 percent of the torque that would exist with the secondaries disconnected in the position shown in (a) to 58.3 percent of this torque in the position shown in (c). The variation in torque for a complete revolution of a two-pole converter is shown in Fig. 2.

With a six-phase diametrically-connected converter, the reduction in torque due to connected transformer secondaries is even greater, due to the presence of three secondaries, instead of two. With a three-phase or delta-connected six-phase converter, the reduction in torque is considerably less, because in no position of the armature does a transformer secondary completely parallel the armature.

The previous explanation refers only to conditions as they exist before the armature begins to turn. As soon as rotation begins, alternating current flows in the armature and transformer secondaries that further reduces the starting torque, due to its demagnetizing effect on the converter field.

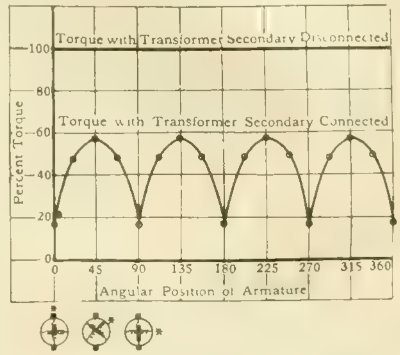

FIG. 2

As a result of both these effects, a converter with solidly connected transformers requires several times more starting current when started from the direct-current side than when the transformers are disconnected.

The obvious remedy in this case is to provide at least one switch in each transformer secondary, and open these switches before applying the direct-current starting voltage. It will be advisable to have the synchronizing equipment on the low voltage side of the transformers.

A further difficulty will arise if the shunt field should be connected directly across the armature. The shunt field should be connected on the line side of the starting resistance, so that full line voltage is applied to the field on the first step of the starting rheostat. If the shunt field is connected across the armature, the field strength, and hence the starting torque, will be weak, due to the voltage drop in the starting resistance. In such a case barring would be of assistance only in overcoming the initial mechanical friction, and the machine probably would not start at all.

Motor Drive in the Preparation of Food

Horace B. Smith

THE PREPARATION and distribution of food is an industry antedated by no other. It is likewise first in importance, as the economic structure of the country depends upon it. The failure of crops directly affects all lines of industry, yet the financial difficulties of other industries are not necessarily reflected upon food production.

In such a large and important industry, it is obvious that the demand for time and labor-saving machinery would soon be felt. From the crude methods of the past, man's ingenuity has devised many time and labor-saving machines. The first indication of this conservation of time and labor is shown in the methods of harvesting, in the early grist mills and in the baking machinery. So broad an industry must necessarily have many divisions.

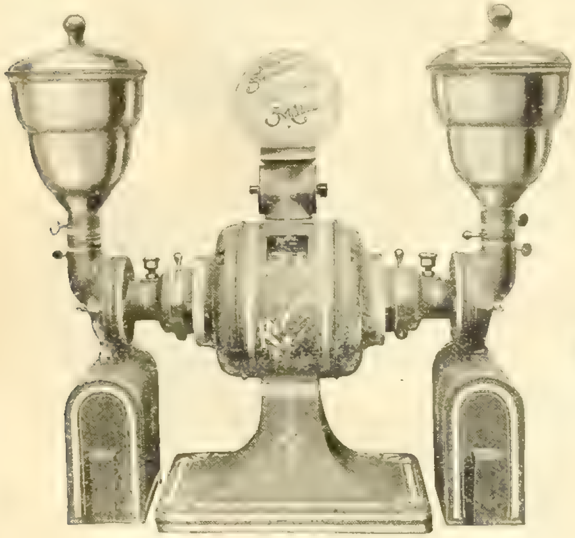

FIG. 1—DOUBLE, MOTOR-DRIVEN COFFEE MILL.
For granulating and pulverizing.

Only a few individually-driven units which are operated by small motors and used in the final preparation of food by the retail dealer or quantity user will be described.

Coffee Grinders—Among the first labor-saving machines to be developed were the coffee grinder and cutter. Until about ten years ago, coffee was usually ground at home in small mills, though some of the more enterprising stores had large hand-power mills and in a few cases a machine belted to a motor. Grinding coffee in the home, is a very laborious task and the motor-driven unit, as commonly seen now in up-to-date stores, gained immediate favor. For a fraction of a cent a pound this time and labor may be saved and coffee obtained in any quantity and ground to the exact degree of fineness which the customer desires. The motor-driven mills of to-day have obtained a remarkable degree of perfection. They are built so that they can be regulated to grind coarse or fine while running. The latest types have indicating regulators to give the grade of fineness desired, and also automatic releases to protect the grinders or cutters from metallic foreign substances. They are further constructed so that they can accommodate other attachments such as spice grinders, peanut-butter grinders, poppy-seed grinders, bone-grinders, etc.

Coffee mills are built in both the single and double mill models and for both counter and pedestal mounting. On the double mill, one end is for granulating and the other for pulverizing. The coffee is placed in the hoppers in the upper part of the machine and passed through the cutters and into the collecting can. The disc for regulating the degree of fineness is at the extreme end of the motor shaft. In some mills, the motors drive

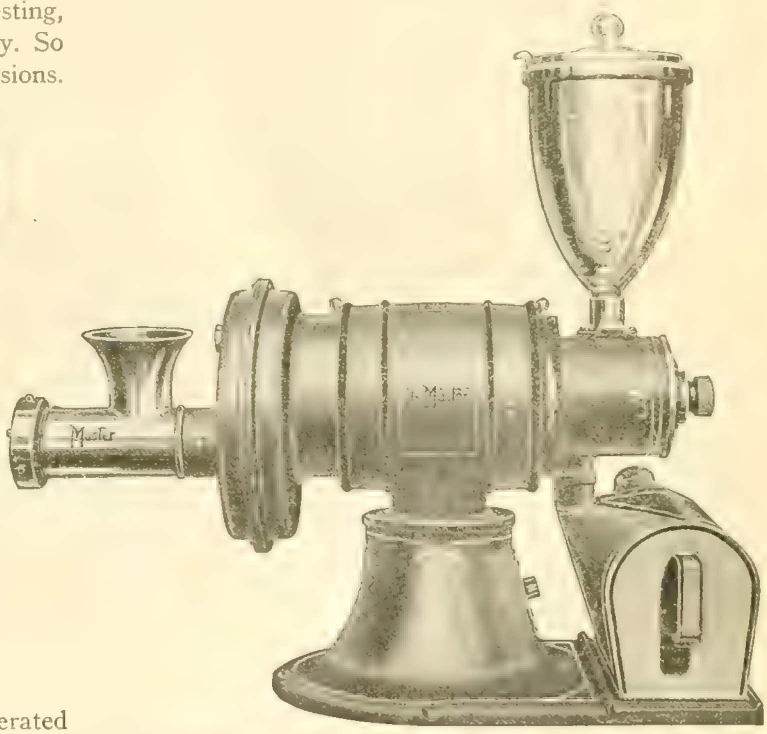

FIG. 2—MOTOR-DRIVEN, COMBINATION MEAT AND COFFEE GRINDER

the burrs directly while in others the speed is geared down. Combination mills are also manufactured for grinding both coffee and meat. Such a machine is shown in Fig. 2.

Some classes of trade demand that the chaff be removed from the ground coffee. A portable blowing machine for accomplishing this purpose consists of a small blower with the necessary hopper and collecting cans. It may be regulated to separate, without loss, any portion of the coffee dust desired. With this machine the merchant can exploit his own brand of coffee.

Coffee Roasters— The progressive grocer in looking around for some method to stimulate his sales has found that the motor-driven coffee-roaster is a good investment. It is estimated that approximately one-half billion dollars is spent annually for coffee in this country. Instead of keeping roasted coffee in stock with every chance of losing its strength and aroma, green coffee can be obtained and roasted fresh every day. The

raw coffee sells for much less than the roasted, hence, the grocer can make a larger profit by roasting his own coffee. Customers who may desire a special blend can be easily supplied by this means.

The green coffee is placed in a cylinder which revolves slowly over a gas or gasoline burner. The time for finishing one charge varies from 25 to 35 minutes, depending upon local conditions and the color of the raw coffee bean. After the coffee is roasted it is placed in cooling pans and when cooled it is ready for sale. The motor, as shown in Fig. 3, operates both the drum and the cooling fan. When the roasting is completed the coffee is drawn out through the lower hopper on the left of the cylinder and placed in the cooling pan. Power is then turned on the cooler by means of the small lever shown in the lower part of Fig. 3 and this operates a blower which drives out any impurities at the same time the coffee is cooled. The machine is equipped with a draft regulating lever in order that the proper heating

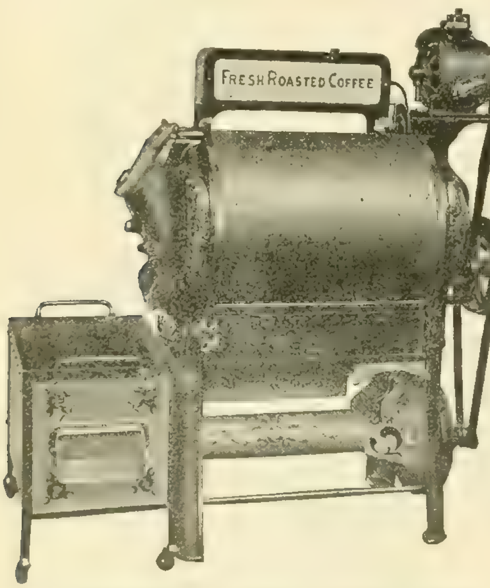

FIG. 3—ELECTRICALLY-OPERATED COFFEE ROASTER

The motor operates both the roasting cylinder and blower.

of the cylinder may be effected without turning the gas down or up from the time the roast is started until it is ready to be discharged into the cooling pan.

Meat Choppers—Another great time and labor saver in extensive use is the motor-driven meat chopper. The old method of chopping-up meat with cleavers was superseded by the hand-power chopper and that in turn by the motor-driven machine. With the old method the butcher would chop a supply of meat during his spare time and the buyer had no choice but to take the meat already prepared. This accumulated stock, however, was subject to considerable deterioration. People have been educated to demand pure food and they prefer to buy their meat, and then have it ground, thus knowing exactly what they are getting. The rapidity with which the electric meat chopper works easily allows this, and in accommodating customers the butcher takes no chance of losing those who are in a hurry. The motor-driven meat chopper is a very useful machine and as it makes a very pleasing appearance, it attracts business. It is very efficient and operates at a small cost. On account of the slower speed necessary, motor-driven meat choppers are geared down to a considerable lower speed than the motor itself.

Meat Slicing Machines have been on the market for a considerable length of time, although the motor-driven ones are of comparatively recent origin. The latest type of machine is entirely automatic, requiring no attention whatever except regulating and starting. The slicing is accomplished by a rotating knife and the travel of the table containing the meat is governed by the thickness of the slice for which it is set. Boneless meat can be placed on such a machine and it can be regulated for cutting from two slices to several dozen slices per inch and for measuring any quantity without stopping the motor. Such machines are used for slicing dried beef, bacon, boiled ham, veal loaf, tongue, etc.

A Peanut-Butter Attachment can be attached to meat choppers and coffee mills. The pleasant taste of peanut-butter has been earning it a great deal of pop-

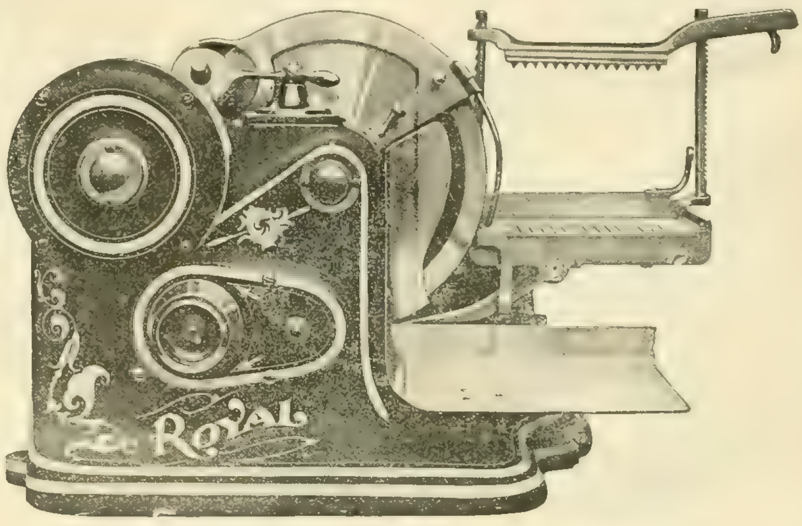

FIG. 4—ELECTRICALLY-OPERATED MEAT SLICING MACHINE

ularity and there has been a large increase in its sale within the past few years.

Ice Cream Freezers—Motor-drive is now universally used in the manufacture of ice cream. Most installations are directly driven and the freezers are adaptable for either ice or brine. Ice cream is becoming generally recognized as an excellent food and the demand for motor-drive for this service is becoming large. The motor usually is direct connected to the freezer, although in small domestic outfits it may be belted. In the portable outfits, the motor does away with all counter shafting, which is very important since cleanliness, increased space, light and ventilation are thereby enhanced. There is considerable speed reduction from the motor to the freezer. The motor starts with a relatively light load but the load increases as the freezing progresses.

Churns—Like all things done mechanically the motor-driven churn is much better and quicker than the manually operated one. For tiresome work churning is perhaps second to none. A typical machine for household use is shown in Fig. 5. The ratio of gears from fly-

wheel to dasher is 4 to 1. This, with a motor speed of 1700 r.p.m. reduced by belts to 70 r.p.m. on the fly-wheel, gives the desired speed of 280 on the dasher. Speed control of the dasher is obtained by means of a tight and loose belt.

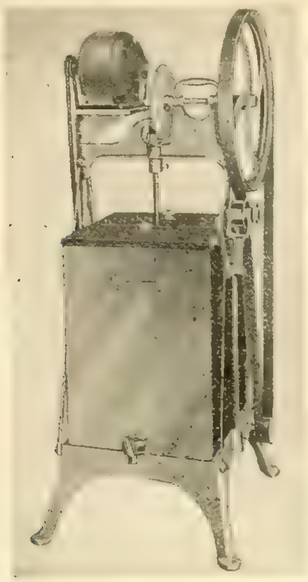

FIG. 5 — ELECTRICALLY OPERATED CHURN
Using splash-proof motor.

Cream Separators, manually as well as power driven, have been in use for a considerable time, but it is only recently that the small motor-driven separator has made its appearance. The use of electric power in rural districts is steadily increasing and with it motor-drive in food preparation. It will soon be a common occurrence to see motor-driven churns, milking machines and cream separators, as well as to see motors generally used in farm work.

Potato Peelers—Very satisfactory motor-driven paring and peeling machines have been on the market

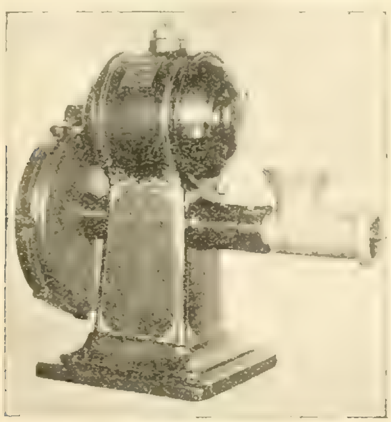

FIG 6— MOTOR DRIVEN MEAT CHOPPER

for several years. It is almost essential to have something of this nature where large quantities of food are to be prepared, such as in military and naval establishments and large hotels. The principle of operation of such machines is both centrifugal and frictional, and one can readily appreciate the large amount of valuable time saved by their use. Although such a machine is applicable for paring beets, turnips, horse-radish, carrots, parsnips, etc., its chief use is for potatoes. Peeling potatoes, besides being very distasteful is extremely wasteful. In the ordinary knife-peeling method, approximately 20 to 25 percent of the potato is wasted, while with the motor-drive, the waste is cut down to less than half of this amount. The machine consists of a cylinder which is stationary and a bottom that revolves. Both the revolving and stationary elements have abrasive surfaces. The charge of potatoes is put into the hopper at the top and water is circulated around them during the grinding process. Since the cylinder is stationary and the disc revolves, every part of the charge strikes both the cylinder and the disc. The disc in such a machine is

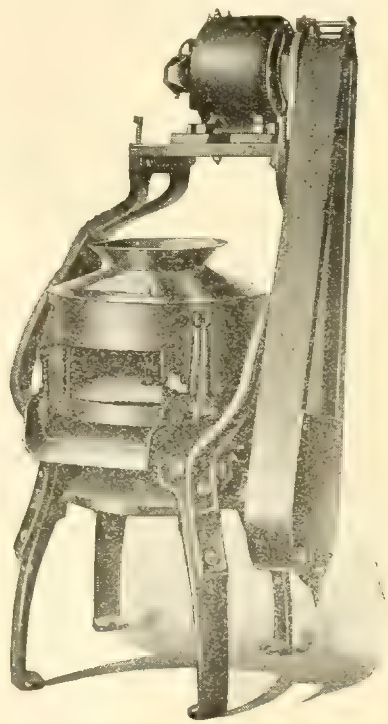

FIG. 7—MOTOR-DRIVEN PARING AND PEELING MACHINE

so arranged that it revolves from 200 to 300 times a minute.

MOTOR CHARACTERISTICS

The motors used for the various applications described, differ somewhat in their characteristics. The smaller machines are for the most part satisfactorily driven by split-phase induction motors, either with or without a mechanical clutch. The heavier machines, however, having a large amount of dead weight to start, are best driven by repulsion-starting, induction-running motors which have a much greater starting torque in proportion to full-load torque.

Curves showing the speed-torque characteristics of these motors are shown in Fig. 8. Curve *CA* is for a split-phase motor without a mechanical clutch while curve *BabA* is for a repulsion-starting, induction-running motor. While the torque of the repulsion-starting, induction-running motor is greater at starting than that

of the split-phase motor, it drops rapidly as the speed increases, so that at the moment of changing over to an induction motor it is less than that of a split-phase motor, as shown by the intersection of *ab* with curve *B*. In the split-phase motor with a mechanical clutch, the char-

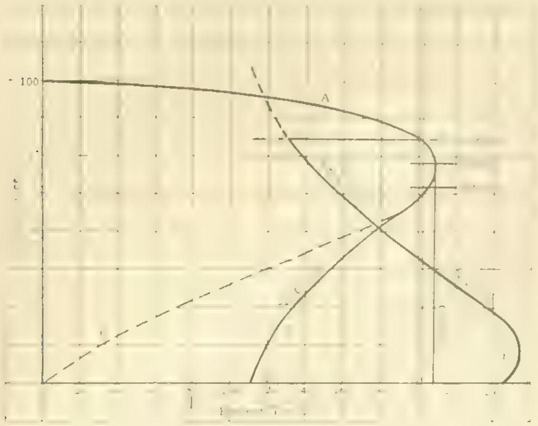

FIG. 8—SPEED-TORQUE CHARACTERISTICS OF MOTORS
Used in various machines in the preparation of food.

acteristics of the shaft of the motor follow the curve *DA* as the maximum, or in other words, the pull-out torque of the motor is available for starting the load.

Curves showing the starting characteristics of the motors are shown in Fig.9. The clutch type motor takes less starting current than the no-clutch motor and also uses it for a shorter period of time than either the no-clutch motor or the repulsion-starting, induction-run-

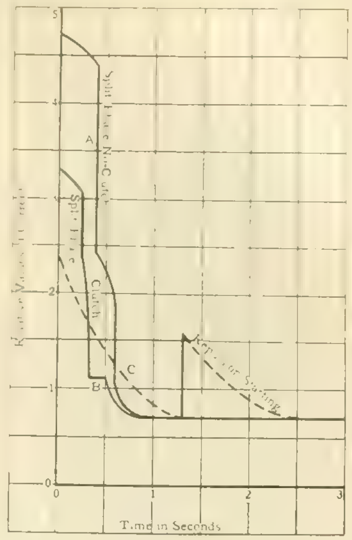

FIG. 9—STARTING CHARACTERISTICS OF MOTORS IN FIG. 8

ning motor. The repulsion-starting, induction-running motor however takes the least starting current possible with a single-phase self-starting motor where no rheostat is used.

ENGINEERING NOTES

Aim—To connect theory and practice

Ratio of Voltage to Starting Torque

When the starting torque T of an induction motor is known for any given voltage V, the voltage V' required to develop some other torque T' may be found from the formula.

$$V' = V\sqrt{\frac{T'}{T}}$$

For example, if the starting torque at full voltage is 2.5 times full-load torque and full-load starting torque only is required, the starting voltage should be,—

$$V' = V\sqrt{\frac{1}{2.5}} = 0.63\ V$$

that is, but 63 percent of full voltage should be applied for starting. The starting voltage should not greatly exceed that required by the torque. The starting voltage is reduced by a starting autotransformer. In sizes of five horse-power and below, it is customary to start the motors directly from the line without reducing the voltage.

Aluminum Catenary Construction

The usual catenary system consists of a contact wire of low conductivity, a supporting cable of low conductivity and a parallel system of feeder cables. In other words the contact system is not depended on for power transmission. While copper contact wires were used in early installations, in most cases where the service is heavy they have been replaced by bronze or steel wires which wear much better, the improved wearing qualities being obtained at the expense of conductivity.

It is obviously desirable to include the necessary conductivity in the catenary system, if possible. This has been done in a 51 mile installation by the Lake Erie & Northern Railway by the simple expedient of wrapping the conductor around the steel messenger cable. This catenary cable consists of seven strands of 0.1118 inch double galvanized extra high strength steel, having an elastic limit of 130 000 pounds per square inch. Around this steel core, fifty-four strands of 0.1118 inch hard drawn aluminum are laid in three layers. This gives a cross-section of 675 000 circular mils of aluminum, having a conductivity of 61 percent; equivalent to two No. 4/0 B & S gage copper cables. The complete cable, including the steel reinforcement, weighs 874 pounds per thousand feet, whereas two No. 4/0 copper cables alone would weigh 1316 pounds per thousand feet.

For the contact wire, a No. 4/0 B & S gage, mild steel, galvanized, grooved wire was chosen, having an elastic limit of 36 000 pounds per square inch. Its coefficient of expansion is only two-thirds that of copper, and its cost about one-third. The contact wire was supported at fifteen foot intervals by stamped galvanized steel hangers. The catenary cable was strung with a deflection of two feet in 150 foot spans. The aluminum strands of the supporting cable are protected from abrasion by sheet steel sleeves provided with flanges somewhat in the shape of a spool, between which the loop of the hanger is free to rise slightly when the collector of the car passes under it, without lifting the catenary cable. The contact wire and catenary cable are connected by a stranded flexible copper conductor every 150 feet.

Joints in the catenary cable were made by steel sleeves of figure 8 section, about eighteen inches long. The ends of the steel cable were slipped into the sleeve from opposite ends, and the sleeve was then given four or five complete twists. Over the splice of the steel core, an aluminum sleeve was placed, whose ends were compressed solidly into the strands of the aluminum conductors by a portable hydraulic press, capable of exerting 100 tons pressure.

By this construction, parallel feeder cables are eliminated entirely and, on account of the high elastic limit of the contact wire, it is expected that no adjustments will be necessary to care for the temperature differences between winter and summer. In addition to the saving of materials, a considerable saving in insulators and labor was also effected.

Blackening of Commutators

Commutators or copper slip rings occasionally become blackened from the action of unidirectional current. The dark color is usually caused by a some sort of action which is present when direct current flows between moving contacts. When current flows from copper to carbon, the commutator face acquires a raw copper appearance; when from carbon to copper, the copper receives a coating of carbon. On commutators, the difficulty can be avoided by staggering the brushes correctly, *i.e.*, so that adjacent brush arms will have the brushes exactly trailing. This same effect occurs on the negative collector rings of large alternating-current rotating field generators, on the positive rings of large homopolar generators, and on the negative rings of homopolar motors, and is much more pronounced when copper brushes are used. That part of a commutator having a medium degree of polish is in normal condition, while the part upon which the positive brush alone trails may be found to be taking very little of the line current.

This blackening of the commutator must not be confounded with blackened bars, which may be found located symmetrically or unsymmetrically around the periphery of the commutator. This is sometimes very bothersome, and the cause of the difficulty is not always easy to find. Any condition which produces one bad spot may tend to produce similar spots symmetrically displaced around the commutator. When one spot is formed, when this spot passes under one brush arm, the brush contacts at this arm are naturally poorer and the other brush arms of the same polarity tend to take the load, and the current density in their brushes is correspondingly increased during this short period. If there is any tendency toward high mica, for instance, then the increased current at these points will produce increased burning away of the copper and burnt spots may develop. If once developed they may gradually travel around the commutator until the whole commutator is black. A local hard or high mica strip may be the initial cause of the trouble, or a rough spot on the commutator may give the same result. But very often, resultant high mica, following the initial cause, tends to spread the trouble. As soon as such black spots are noted, further trouble frequently can be headed off by scraping or cutting the mica below the copper surface in the burnt regions.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor

JANUARY 1918

Installation of Air Piping to Prevent Freezing

Due to the large number of air-operated mechanisms which are used on railway equipments, it has become necessary to take great precaution in the installation of the air piping between the compressor and the main reservoirs to prevent freezing of the condensed moisture. This is especially true of pneumatically-operated apparatus which employs valves with small openings. Contrary to a general impression, freezing at very low temperatures is not so troublesome as at a little below 32 degrees F. because, at lower temperatures, most of the moisture has been frozen out of the atmosphere. At 32 degrees F. the moisture carried over from the compressor is therefore greater than at the lower temperatures. The installation of the air piping should be such that the maximum amount of moisture is retained in the main reservoir. No pockets should exist where moisture is liable to be retained, as freezing will occur wherever a small body of water collects in the piping.

FEED PIPE

The pipe between the compressor and the main reservoir as well as the pipe between the two main reservoirs should be at least 25 feet long and when the length of car does not permit a straight run, the pipe should be made up in the form shown in Fig. 1. This method of piping gives a maximum of cooling with minimum space.

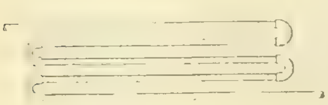

FIG. 1.

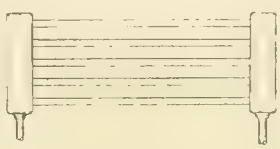

FIG. 2.

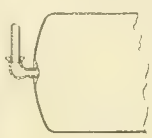

FIG. 3.

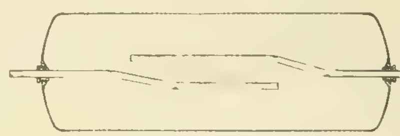

FIG. 4.

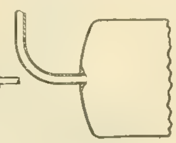

FIG. 5.

A scheme which is similar to the pipe coil but having the additional advantage of multiple paths, is shown in Fig. 2. With this arrangement, a number of tubes are fastened into two heads or drums. One of these drums can be used as a moisture trap, preventing the major portion of the moisture from getting into the main reservoir. This advantage however is offset by the ease with which the moisture can be more thoroughly drained from the main reservoir. For a given length of piping of the same diameter in the two systems, one aranged in a single path and the other in multiple paths, the single path will require a greater velocity and hence a greater loss in pressure for the delivery of a given quantity of air. This means that, for a given main reservoir, the compressor must pump against a greater pressure with the single path system, because of the greater friction. This higher pressure is accompanied by a higher temperature and consequently, even though the radiating surface of both arrangements of piping be the same, the air from the single path of pipe, in view of its higher initial temperature, must necessarily be warmer when reaching the main reservoir than with the manifold arrangement. The extent to which this difference exists depends upon the size of pipe and upon the quantity of air delivered in a given unit of time.

CONNECTIONS

In connecting the feed pipe to the reservoir, particular attention should be given to make sure that the connections do not give a reduction of pipe area at any point, as a change in area increases the possibility of freezing. One of the most common breaches in the proper method of making an air installation is to use an "L" fitting at this joint, which not only gives a reduction of area but forms a trap for moisture to accumulate, as can be seen in Fig. 3. This difficulty, however, should not exist, because most manufacturers of air reservoirs tap the reservoirs for pipe connections of ample size. A better and much more satisfactory scheme for this connection is to have a straight run or large radius bend to the main reservoir where possible and use a connector which does not give a reduction in area, as shown in Fig. 5.

A moisture trap which can be arranged in conjunction with the main reservoir is shown in Fig. 4.

PIPING TO APPARATUS

All piping from the reservoir to the various pieces of apparatus should be aranged to drain back into the reservoir as far as possible and when this is impossible it should at least drain away from the apparatus.

INTAKE

There have been a number of installations where the compressor intake has been mounted inside of the car, and in some cases it has been mounted underneath the car. The best place to mount the intake is on the roof of car, as it is then possible to obtain cool, clean air. With the intake mounted inside of the car, a greater percentage of moisture is obtained, which is always to be avoided. More moisture is obtained from the interior of a car than the exterior on a cold day, because the higher temperature of the air within the car, permits the presence of more moisture per unit volume of air than in the air outside of car.

INSPECTION

Even with the best of installations it is impossible to prevent considerable moisture from getting into the system. To prevent trouble from this source, a rigid inspection should be maintained during the winter. It is a good practice to drain the main reservoir at least once a day, and oftener if possible. Some interurban roads operating between terminals make a practice of draining after each round trip.

The Journal Question Box

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1547—Special Transformer Connections—I am contemplating the installation of two 75 kw. transformers with Scott taps brought out of the primary windings and the general scheme of connections as shown in Fig. (a). This outfit is to be used in connection with a centrifugal pump test floor, for testing pumps with their direct-connected motors. We encounter motors of 110, 220, 440, 550 and 2300 volts both two-phase and three-phase, but the majority are 220 and 440 volts, two and three-phase, which could be taken care of by the connections shown. It seems to me that the 110 and 550 volt motors could be taken care of with an autotransformer, with taps brought out as shown in Fig. (b), using the same autotransformer for both two-phase and three-phase service. Aside from the autotransformer, which I imagine would have to be of a special design, the outfit involves only standard apparatus which could be purchased at current prices and short-time delivery. I would highly appreciate any suggestions or criticism of this plan, or the suggestion of some different and better scheme for accomplishing the same results. A.B.C. (WIS.)

The schemes of connections shown by Figs. (a) and (b) should give good results. The scheme shown by Fig

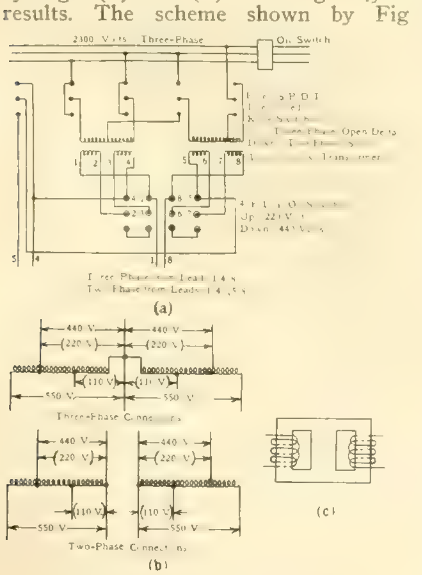

FIG. 1547(a), (b) and (c)

(b) will require two single-phase autotransformers, one for each side, or if one unit is used it must be of special construction so as to provide for two magnetic fields, 60 degrees out-of-phase when operating three-phase, and 90 degrees out-of-phase when operating two-phase. This can be accomplished by placing the two windings on two cores of a three-core construction as indicated by Fig. (c). The middle core should be 40 percent larger in cross-section than the cores on which the windings are placed. Figs. (a) and (b) provide for all voltages mentioned except 2300. The 2300, three-phase, can be taken from the line and the 2300, two-phase can be obtained from the outside connections of primary side of transformers opposite points 8, 5, 4 and 1 in Fig. (a). The single-pole, double throw switches should be in the down position for two-phase, 2300 volts. J.F.P.

1548—Transformer Operation—Please explain the reasons for the results obtained on the two banks of transformers shown in Fig. (a). All the load on these transformers is between the outside wires and the neutral. Referring to Fig. (a), this bank of two

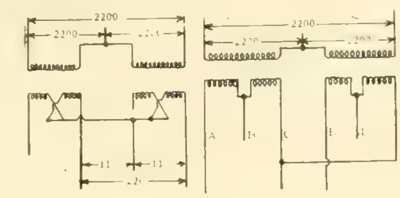

FIG. 1548 (a) and (c)

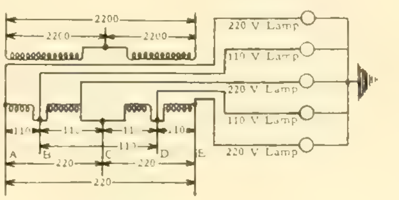

FIG. 1548 (b)

transformers has its primary windings connected in open-delta, and secondaries connected to the 110 volt—220 volt, three-wire lighting feeders. If these connections are correct for the result obtained, would it not be possible to connect both halves of the secondaries in parallel and thus use the transformers to their full capacity? Would the placing of a load across the 220 volt mains have any effect on the performance of the transformers? The transformers are presumably connected as shown in Fig (b). This should give 110 volts, three-phase; 220 volts, three-phase on open-delta, or two 110 volt—220 volt, three-wire systems. However, the actual voltages measured across the busbars with test lamps are approximately as follows: *A-B* 110; *A-C* 220; *A-D* 330; *A-E* 440. A ground on busbar *A* or *B* would cause the opposite ground lamp to be blown out. If the secondary leads of one transformer were reversed as shown in Fig. (c), would that explain the voltages obtained? O.F.H. (ALBERTA)

The connection shown in Fig. (a) is open-delta with one phase of the low-tension reversed, which causes the voltages, on the low-voltage side, to be 120 degrees apart. This connection gives 110 volts between outside and middle wires and $1.73 \times 110 = 190$ volts between the two outside wires. If 110 and 190 volts are satisfactory, the two halves of the low-voltage winding can be connected in parallel with the result of increased capacity from the transformers. The transformer bank will have somewhat poorer regulation for loads connected to the 190 volt leads than for loads on the 110 volt leads. A load connected to the 190 volt leads will produce a slight drop in voltage across the 190 volt as well as the 110 volt leads, but this reduction in voltage, in general, should be of little importance. Transformers connected according to Fig. (b) should give 110 and 220 volts, three-phase, open-delta, or two 110-220 volt, three-wire circuits as stated in the question. If one phase is reversed as indicated by Fig. (c), then the voltages should be as follows: *A-B* = 110; *A-C* = 220; *A-D* = 292; and *A-C* = 381. It is probable that the bank was connected according to Fig. (c) and that the voltages *A-D* = 330 and *A-C* = 440 as measured with lamps are in error. J.F.P.

1549—Enamel for Rotor Bars—Can you furnish a formula for the enamel used to insulate rotor bars? We have several 75 and 100 hp motors which are insulated with fish paper, but which do not stand up like enameled bars. F.W. (TENN.)

There are a number of insulating varnishes on the market suitable for insulating rotor bars. The main characteristic required for such a varnish would be a tough, long-life film when baked. Two good varnishes for this class of work are known as "Amber Insulating Varnish" and "Black Asphaltum Enamel M 1955." These varnishes require baking at a temperature of 110 to 125 degrees C. four to eight hours. L.T.F.

1550—Locking of Induction Motor—What is the explanation of the "locking" that occurs in an induction motor where the number of stator and rotor slots have a common divisor? What effect, if any, would different stator and rotor windings have on this locking, *i.e.*, whether two, three or split-phase stator, and squirrel-cage or wound-type rotor. Would completely closed rotor slots eliminate the trouble? What effect on the performance would such rotor slots have? G.P.S. (MINN.)

The rotor and stator tend to move into a position which will allow the most magnetic flux or in other words, to a position in which the reluctance of the air path is a maximum. To move it from this position will require a torque proportional to the flux, and evidently the motor will lock unless its starting torque in this position is greater than the locking torque. A squirrel-cage motor will have less tendency to lock than a wound-rotor motor due to the short-circuited winding tending to distribute the flux evenly. A split-phase motor will lock more easily than a two or three-phase motor because it naturally has poorer starting torque, although with

equal torques at start, there should not be any difference in the primary circuit. Closed slots would not have any one position of rotor which would give a materially lower reluctance of the air-gap than any other position, provided the bridges over the slots did not become saturated. Closed slots would not produce dead points but they would decrease the pull-out torque of the motor considerably. To prevent locking, the number of primary and rotor teeth and their size must be so proportioned that the reluctance of the air-gap will be as nearly constant as possible all around and for all positions of the rotor. C.W.K.

1551—[illegible] TRANSMISSION LINE—Fig. (a) shows a locomotive haulage at 275 volts direct-current, on which several locomotives and direct-current air compressor motors are working. Part of the installation is completed and the power is supplied by two 300 kw, 275 to 300 volt generators; further installations are to be made and are to be taken care of by one 300 kw, 275 to 300 volt generator. Fig. (a) shows the amount of copper and steel now in use for feeders and the location of the various loads. It is desired to have the two substations operate in parallel. What size of wire is most desirable (in the locations shown) to get best parallel operation of the generators? H.M.J. (PA.)

The load on the two generating stations should divide in proportion to their capacities. The 600 kw station would then supply 2200 amperes and

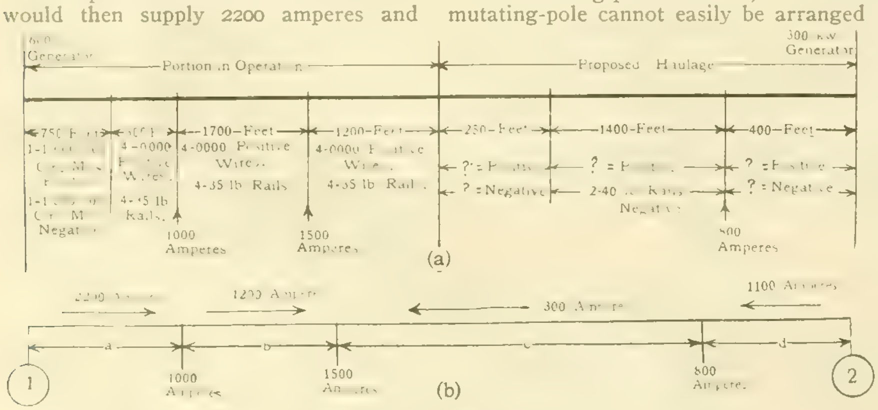

FIG. 1551 (a) and (b)

the 300 kw station would supply 1100 amperes. If the voltage [illegible] the two stations are equal, the [illegible]age drop between them is [illegible] gives [illegible] $300 R_c - 1100 R_d$ [illegible]

R_a and R_b are determined from the conductor sizes in the two sections nearest to the 600 kw station. R_d can be determined if the conductor in this section is made of sufficient size to carry the current. This then leaves R_c to be found. It is made up of 1200 feet of 4/0 wires and four 35-pound rails; of 1400 feet of two 40-pound rails and 1900 feet of conductor of size to be determined. Subtracting the known parts leaves only the resistance of the 1900 feet of conductor. Probably the size thus found will be smaller than can handle the currents which will flow under operating conditions. In this case it will be necessary to adjust the compounding on one of the stations so that the difference in voltage under load will not be zero but will be such as to cause the loads to divide proportionately to the capacity. The difference necessary may be computed from,—

$2200 R_a + 1200 R_b - 300 R_c - 1100 R_d = E_1 - E_2$. A.W.C.

1552—COMMUTATOR SEGMENTS—The adjacent segments on the commutator of a 50 kw, six-pole generator are of different colors, every other segment being of the same color. The segments look as if they were heated unequally. The generator has a two-circuit, wave-wound armature of 112 coils and 56 slots. It is direct-coupled to a steam engine running at 300 r.p.m. What is the reason for this phenomenon? H.W.A. (MO.)

The probable explanation of the phenomenon is that the armature coils of the machine are not evenly distributed around the periphery, but are grouped in pairs in slots. As a result of this, two coils cut the same flux almost simultaneously if they lie in the same slot, but at different times if in different slots. Since these coils are connected to commutator bars of uniform width, they commutate at regular intervals. This means that the commutating zone of one coil of a slot, is displaced somewhat with respect to that of the other coil in the same slot. The main field reverses in polarity in the neutral zone, and therefore has different effects on opposite sides of the neutral. Since the two coils of a slot commutate at different positions, they are unequally affected by the main field while short-circuited by the brush. In the case of a commutating-pole machine, the commutating-pole cannot easily be arranged to take care of this difference, and if the commutating-pole flux is correct for one coil, it will not be quite right for the other. This results in one coil commutating a little poorer than the other, and if the difference is sufficient, it may manifest in a discoloration of every other bar. This phenomenon is even more likely to occur in the case of a multiple-wound, non-commutating-pole machine with several bars per slot. Undercutting the commutator mica has been known to make machines less sensitive to such conditions. F.D.N.

1553—CAUSES OF NOISE IN INDUCTION-MOTOR—We have a 30 horse-power, three-phase, 2300 volt, induction motor which takes four amperes more on one phase than on either of the other phases. The motor makes a noise at times, depending on its load and voltage. Under light load and higher voltage the noise is very loud. As far as we can see the rotor is not striking the stator. Fig. (a) shows how the motor is connected and by what ammeters we take our reading. J.A.P. (MINN.)

The main load on the generator, aside from that due to the induction motor, may be unbalanced, and in this case, the motor would tend to balance the load. For this reason the readings of the ammeters when located as shown may not be a true indication of the amount of unbalancing due to the motor. An induction motor of the rating given should take about eight amperes per terminal at full load. Assuming that the motor is actually re-

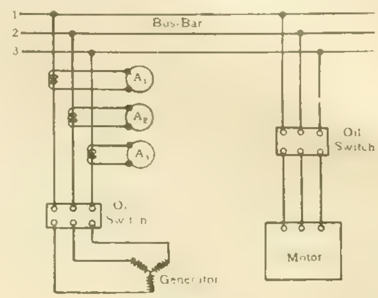

FIG. 1553(a)

sponsible for all the unbalancing indicated by the ammeter readings, it would seem that the motor was running under light load or no load when these readings were taken since the readings show that two phases of the motor are taking four amperes and the third phase, eight amperes. Two possible causes of this unbalancing in the motor are:—First, the third phase of the motor may be connected so that it has twice the number of parallels or one-half the number of turns in series that the other two phases have. This condition would cause a serious unbalancing at light loads or no load and high voltages, as the third phase, with only one-half the series turns that phases one and two have, would take twice the magnetizing current that phases one and two would take. This unbalancing of the currents in the three phases would in turn produce a distorted magnetic field and this distorted field would result in a noise such as mentioned in the question. The unbalancing of the currents would also produce unequal heating of the motor. Second;—a part of the coils in the third phase may be short-circuited. This also would reduce the number of effective turns in the third phase and to that extent have very much the same effect as outlined above, besides producing a further unbalancing of the currents due to the fact that the short-circuited coils would act like a short-circuited secondary of a transformer. In this case there would tend to be excessive local heating. G.T.S.

1554—STORAGE BATTERY CHARGING—A storage battery is rated to be charged at 90 amperes. What difference will it make if it is charged at 110 amperes continuously? Will this shorten the life of the battery in any way? If the battery is using too much water, what is the cause of it? What is the trouble with it if it is charging too slowly when the solution is good and what is the best way to boost it without damage to the cells? This is a mine battery locomotive. F.K. (PA.)

Judging by the 90 ampere charging rate, the battery in question is of the Edison type. It is permissible to charge an Edison battery at any rate as long

as the temperature of the electrolyte does not exceed an actual temperature of 115 degrees F. at the hottest point which is usually near the center of each cell. If the 115 degrees F. temperature is not exceeded, the life of the battery will not be materially affected. If the battery is requiring more water than normal, it is probably being charged too frequently or the temperature of the electrolyte is allowed to increase above 115 degrees F., either during the charging or discharging periods of the battery. If the specific gravity of the electrolyte is normal, namely, 1.170 to 1.100 and the battery does not develop full capacity after receiving a complete charge at the proper rate for the proper length of time, then there are but two conclusions:—first, the battery is approaching the limit of its useful life when the elements must be renewed, or second, the battery has previously been charged at a rate less than the normal rate prior to the last charge at the normal rate.
A.M.C.

1555—TEMPERATURE MEASURING DEVICE ON ALTERNATORS—I have read with great interest Mr. B. G. Lamme's article entitled "Temperature Distribution in Electric Machinery" in the February '17 issue. Mr. Lamme's article seems to indicate that he is much in favor of the thermo-couple in preference to the resistance coil for measuring temperature. As a matter of general interest I would like to know how extensively the thermo-couple and resistance coil are being used at the present time, that is, are all of the prominent electrical manufacturers equipping their generators with either one or the other?
H.B.J. (ILL.)

Some form of internal temperature measuring device is now very generally used for the larger alternating-current generators, particularly those directly driven by steam turbines. The standardization rules of the *A.I.E.E.* specify that all generators having cores 20 inches wide, or more, shall have an internal temperature measuring device installed. The Westinghouse Company is now following this practice in its turbogenerators, and we understand that the General Electric Company is also following it.
F.D.N.

1556—RECONNECTING INDUCTION MOTOR—I was called upon to reconnect a 50 horse-power, 60 cycle, 220 volt, squirrel-cage induction motor for 25 cycles, 440 volts and to retain the same horse-power. The speed may be 1500 r.p.m., present no-load speed 1200, full-load speed 1165. It was originally connected in parallel-star with the coils in each group paralleled. I changed to single star and connected the coils in each group in series and made it a two-pole machine. The coils are form wound. These changes have resulted in the motor heating beyond a safe point on "no load." If it is the lack of iron which prevents this change, would it work if wound for 40 horse-power, 25 cycle, 440 volts?
A.A.K. (ILL.)

The trouble is with the "throw" or "pitch" of the coil and is explained in the JOURNAL for February 1916 under the subheading "chord factor." The span of the coil must be somewhere near the distance from the center of one "North" pole to the center of one "South" pole, or 180 electrical degrees, and should never be less than one-half this distance. In the case referred to above, the original throw of the coils was right for six poles or a little less than one-sixth of the circumference of the inside of the stator core. When reconnected for two poles, the coils would then span less than one-third of a pole pitch or less than 60 electrical degrees. The effect of this is to very greatly reduce the counter e.m.f. which the coils will generate with the same field flux. Since a counter e.m.f. approximately equal to the line voltage must be generated in any case, this results in making necessary an increased field flux or more magnetism in the iron and an increase no-load current. The effect of the increased magnetism is to increase the iron loss and the effect of the increased no-load current, which is the magnetizing current, is to lower the power-factor when the machine is loaded and this in turn increases the copper loss. The effect of increasing the iron loss and the copper loss is to increase the heating. This is explained in the Feb. 1916 article and a factor is given to show the effect on the generated counter e.m.f., of chording the coil. In general, the throw of the coil should not be less than one-half of the pole-pitch or disturbances in the shape of the magnetic field will result in addition to the troubles already mentioned. In changing from one number of poles to a smaller number, the iron below the slots is worked harder since the total magnetic field in the machine is divided into a smaller number of magnetic circuits with the result that there is more magnetism at any given point in the core below the slots. This causes the core iron to work harder to carry the increased flux and causes increased iron losses. Changing from six to two poles would be enough to cause trouble even if the throw of the coil was nearly correct. The remedy will be a new set of coils with the proper throw and number of turns and even then the horse-power will probably have to be cut in half due to the core section below the slots not being sufficiently large for a two-pole motor. The short-circuiting rings on the squirrel-cage motor will also have to be changed since their cross-section is not great enough for the two-pole current.
A.M.D.

1557—END SHAKE ADJUSTMENT OF INDICATING INSTRUMENTS—Please explain the adjustment for end shake on portable indicating instruments of the electrodynamometer type. How much end shake is proper?
F.L.B. (PA.)

There are two adjustments at the upper end of the shaft of the electrodynamometer type meter. One of these is a jewel screw which holds the shaft and regulates the end shake. The other is a set nut on the jewel screw, which in most meters locks the spring adjustment for zero setting. To change the amount of end shake, it is necessary to loosen slightly the set nut, then turn the jewel screw in or out, and retighten the set nut. The method of adjusting the end shake is to turn in the jewel screw, moving the shaft lightly until the end play just disappears; then the screw is backed out about one-fourth revolution. As the pitch of the jewel screw is usually 80 threads per inch, this will give an end shake of about three mils. After making this adjustment, the spring should be turned to adjust for a zero setting again.
H.V.S.T.

1558—REACTANCE COILS—What is considered good practice, to use, or not to use, choke coils at the junction of overhead and underground feeder systems? Fig. (a) illustrates the point in question. Please explain action of abrupt surges in each case.
[illegible] (ONTARIO)

The use of choke coils for protecting cables is not to be recommended for the reason that choke coils possess considerable inductance, while cables usually have little inductance and have high electrostatic capacity. The combination

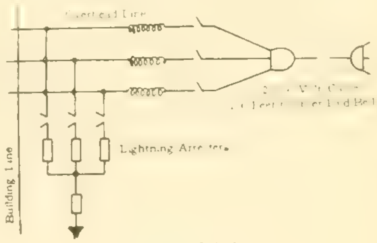

FIG. 1558(a)

of inductance and capacity in series is liable to produce a condition of resonance in which a greater potential may occur over each than over both in series, as these potentials may be nearly opposite in phase. A great many systems, as for instance the case at hand, have a combination of cable and overhead lines. In view of the above generalization, the question at once arises whether or not the system in question should be considered as a cable system or not. In determining this, there is no hard and fast rule, it depends upon the relation of the inductance and capacity of the system. One of the large manufacturing concerns has considered it good practice to consider all lines with more than one-half mile of cable as a cable system and that in such cases choke coils should not be used either at the station or at the junctions of the cable and overhead line; and that a system with less than one-half mile of cable is not a cable system and choke coils may be used. In this particular case, we would consider it good practice to place an arrester at the junction point of overhead and cable systems. Abrupt surges striking a cable that is not protected by choke coils are by no means as dangerous, as when they strike pieces of apparatus that are inductive. This is assuming that the insulation in the two cases is equal. In the case of an inductive piece of apparatus, the progress of the surge is suddenly impeded and the voltage piles up at the terminals of the apparatus and may cause a failure of insulation. On the other hand, when an abrupt surge strikes a device of high electrostatic capacity, like a cable, it meets with the opposite of impedance and is flattened out. The cable thus tends to protect itself against abrupt surges, and this is the reason why choke coils can be omitted in connection with cables with reasonable safety, entirely aside from the fact that the choke coils might cause trouble in the case of other surges. This tendency of a condenser to flatten out a surge and reduce its voltage has been taken advantage of, both in this country and

abroad, by the use of electrostatic condensers as lightning protective devices, particularly on direct-current circuits.

G.C.D. and Q.A.B.

1559—PHASING-OUT TRANSMISSION LINES—What methods do you recommend to phase-out 60 000 volt transmission lines which originating from one source of power, have been stepped up and down several times finally resulting in two voltages the same to tie together, completing a loop. A simple illustration of what is desired is shown in Fig. (a). How will the high and low sides of bank 3 have to be connected to tie lines 1 and 2 together. If the transformers at bank 3 can be so arranged, how can the 24 000 volt sides be phased-out to tie together at this point?

[illegible] (KANS.)

If it is possible to trace out each conductor from the common 4400 volt bus up to transformer bank 3, the connections at this bank should be made as shown in Fig. (b). If it is impossible to trace out each conductor, then the following method is suggested. Connect the transformer in delta on the 24 000 volt side and in star on the 66 000 volt side. Close switches on the 66 000 volt side leaving the 24 000 volt side disconnected from the 24 000 volt line. Connect a static voltmeter between the 24 000 volt line and the 24 000 volt side of the transformer in such a way as to measure only a part of the line potential for safety and convenience. This may be done by connecting the static voltmeter to the cap of the second suspension insulator (counting from the cross arm) as shown by the full lines in Fig. (c), or in case of pin-type insulators, to the rim of the lowest petticoat as shown dotted in Fig. (c). The conductors producing no positive deflection of the voltmeter are of the same phase and should be connected to the terminals of the oil circuit-breaker controlling said phase. See article on "Phasing Out High-Tension Lines" by E. C. Stone, in the JOURNAL for Nov. '17, p. 448.

M.H.C.

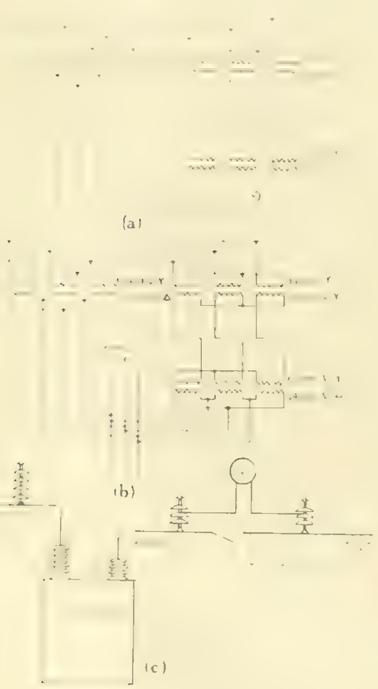

FIG. 1559 (a), (b) and (c)

1560—LIGHTING INSTALLATION— It is desired to install thirty-six 550 watt Mazda C units in a machine shop. The building is 400 feet long and 50 feet wide. Lamps are to be suspended from the lower edge of the roof trusses which are 20 feet apart and lamps are high enough to clear the crane. It is proposed to control the lamps in groups of four from the lighting cabinet located near the entrance. One group is about 250 feet from the cabinet. No. 8 wire would cause a drop of about five volts at these lamps. Would it be advisable to allow that much drop using 110 volt lamps, and reduce the size of wire for the groups near the cabinet so as to maintain five volts drop all over the shop, or would it be more satisfactory to use the same size wire throughout and use higher voltage lamps near the cabinet? Can you suggest a more satisfactory arrangement?

P. J. (OHIO)

The saving of copper would not justify the variation of five volts on the system. Good regulation is of prime importance in a successful lighting installation. The voltage variation really should not exceed two volts. The use of No. 6 wire on the group which is 250 feet from the cabinet would probably cause a drop of from two to three volts. The use of the same size of wire throughout or higher voltage lamps near the cabinet is not a proper arrangement. Care may be exercised at first by the attendants but is only a question of time until the lamps are used in the wrong sockets and the general performance of the system will be faulty.

A.B.

1561—MOTOR WINDINGS—(a) I have a 20 horse-power, three-phase, eight-pole, 440 volt, 900 r.p.m. motor with three coils per pole, that was connected one-circuit delta, span 1—10. I changed this winding to a three-phase, 440 volt, 60 cycle, 1200 r.p.m., four coils per pole, six-pole machine with a two-circuit, star-star winding, span 1—10. I have noticed, ever since I have reconnected this motor, that it seems to take more current than it did before it was changed. The 20 horse-power starter that was on it before does not seem to be large enough now to handle the current, as it burns the drum and finger contacts more now than before. The autotransformer coils in the starter for the starting current do not seem to be large enough either, although they are both connected on the highest tap on service. The writer is under the impression that changing this motor from 900 to 1200 r.p.m. increases the exciting current, also the horse-power of the machine, and, that the auto starter coils are not large enough for the starting circuit required now by the motor. Is it best to install a larger starter of about 30 horse-power or so? Also what horse-power will the motor develop by this change? (b) I have also a three-phase 60 cycles, 220 volt wound-secondary motor, connected two parallel star, that I would like to change to a two-phase, 440 volt connection. I find by my tables that a two-phase 440 volt connection cannot be had as the nearest to it would be 356 volts, and this motor would probably have to run on 480 or 500 volts. Would the insulation and motor stand for the increase of voltage from 356 to 480-500? (c) I have also a one-half horse-power, 1800 r.p.m., 48 slot, 24 coil, one conductor per slot, span 1-12, four-pole, single-phase motor which has a phase-splitter or starting box. Please explain how to connect this motor for 110 and 220 volts without a phase-splitter, and how the ordinary knife switch could be used for starting with pulley and belt.

E.M.D. (WASH.)

(a) In any induction motor, the rotating magnetic field can be conceived to be cutting the stator coils and generating in them a back voltage or counter e.m.f. of practically the same value as the voltage applied from the line. Reconnecting the six poles causes the magnetic field to rotate four-thirds as fast and consequently to generate four-thirds as much voltage. Consequently the line voltage should be raised to four-thirds its original value or 585 volts. Reconnecting from delta to parallel-star would thus make $\frac{1.73}{2} \times 585 = 508$ volts. Since the throw of the coil is unchanged a chord-factor of 0.92 is introduced due to the coil spanning only nine-twelfths of the pole-face on the six-pole connection. This reduces the line voltages again to $503 \times 0.92 = 466$ volts or nearly right for 440 volts. The only thing to disturb this would be the fact that the iron back of the slots is working harder on six poles than on eight poles, since the total magnetic flux is assumed to be the same and since it is divided into eight circuits in one case and only six in the other. Hence in any cross-section of the core back of the slots there is eight-sixths as much magnetic flux with the six-pole connection. This may cause saturation and higher no-load current and poorer power-factor and hence higher full-load current. However, assuming that this saturation is reasonable, the horse-power on the six-pole connection will be increased about as the speed or say to 26.67 horse-power. Since the line voltage remains at 440 the auto-starter has to carry 33 percent more current, and this probably accounts for its operating at a higher temperature. (b) No, the motor will not operate properly. No well designed motor will stand an increase of its operating voltage much over ten percent. See article on "Effect of Voltage or Frequency Variation on Induction Motor Characteristics" by L. W. Smith in the JOURNAL for March '17, p. 105. (c) The running winding is in two sections marked A_1 — A_2 and B_1 — B_2. For 220 volts connect A_2 and B_1 to one line and A_2 and B_2 to the other line. In either case, if the motor is to be started by hand as described, the two ends of the starting winding C_1 and C_2 should be taped as there will be a voltage generated in the starting winding after the motor is up to speed and the two ends may become short-circuited unless insulated from each other.

A.M.D.

CORRECTION

On page 359 of the JOURNAL for September '17 at the top of the first column the fraction $\frac{19.7}{10^6}$ should read $\frac{23.6}{10^6}$

THE ELECTRIC JOURNAL

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Design Limits of Commutating Machines

There has been a more or less general feeling for some years that the day of the direct-current generator is past, and that the importance of the work and the demands on the skill of the direct-current machinery designer have considerably decreased. With the concentration of power production in large central stations, with the disappearance of reciprocating engines in favor of turbine units of five and ten times their capacity and the almost universal use of alternating-current generating units, the direct-current generator has practically disappeared as a primary source of electric power. This has probably been the basis of the feeling mentioned but, while the importance of commutating machinery has, without question, decreased in the field of generation, it has greatly increased in the transformation and utilization of power.

At present, direct-current motors capable of exerting 2 000 000 foot-pounds torque (corresponding to 15 000 horse-power at maximum speed) and capable of reversing from full speed in one direction to full speed in the other direction in one second are operating reversing blooming mills in many of the largest mills in the country and playing no small part in enabling the steel industry to meet the unprecedented demands now being made on it; direct-current hoist motors are running some of the largest capacity hoists in deep mining operations; the expansion of the Navy's submarine program has given direct-current designers a new and interesting problem; and the acknowledged advantages of direct-current in the propulsion of cars and trains has led to a most difficult problem in designing motor-generator sets for high voltage railway service. These new applications for direct-current machines give the work of the direct-current designer an importance and variety, and require a degree of skill that makes an appeal to the ablest men looking forward to electrical machinery design as a vocation.

These observations have been suggested by the interesting article on the design limits of direct-current machines by Mr. Hague in the present issue of the JOURNAL. Mr. Hague wisely emphasizes the fact that the limits he discusses are limits only in the sense that they mark the present boundaries of our knowledge of the theory involved and of our skill in design and construction. These boundaries have advanced year by year in the past and may reasonably be expected to advance still further in the future. If these so-called "limits" are considered merely as shifting "boundaries" a better attitude of mind toward changes in speeds, voltages and other characteristics will follow. The limits existing five years ago required that a 1000 kilowatt, 600 volt generator be designed with a speed not exceeding 600 r. p. m. Today with the extension of limits this maximum speed has been increased fifty percent.

It is significant that the greater part of Mr. Hague's article is concerned with commutation and commutators. It seems to be a habit of commutators to monopolize attention. It is a fact that limits are more often imposed by commutation, particularly in the higher speed ratings, than by heating. This also explains why the rating of direct-current machines has been more difficult than of alternating-current machines, where capacity is limited mainly by heating. In direct-current machines both commutation and temperature are important limits and the method of rating must be determined partly by the characteristics of the unit and partly by the service requirements.

F. D. NEWBURY

What Is Electrical Porcelain?

In the early days of electric power development glass was the material resorted to for line insulation, because engineers were familiar with its use on telegraph circuits. When made in larger sizes and subjected to higher voltages, however, glass betrayed certain weaknesses, and necessity compelled a resort to porcelain on account of its greater resistance to breakage from stresses due to temperature changes, its somewhat superior weathering qualities, and the comparative ease of manufacture in larger sizes.

It is true perhaps that some of the earlier electrical porcelain resembled Kipling's "Bloomin' idol made o' mud" celebrated in "The Road to Mandalay" and did not justify our faith in it. Modern electrical porcelain, however, is fabricated on logical formulae based on an analysis of the desirable qualities and the possibility of obtaining these qualities with the materials available. In the current issue of the JOURNAL Messrs. Gilchrest and Klinefelter have described, in a very interesting and convincing way, how a reasonable balance has been obtained between mechanical strength, dielectric strength, resistance to moisture absorption and resistance to fracture from sudden temperature changes.

Well-made electrical porcelain is a quite satisfactory product when used with proper consideration for its limitations. Like many other elements of electrical equipment, real progress has been and is being made by detail refinements as a result of accurate knowledge based on careful research. Such technical knowledge is of immediate value in two ways. First, it permits, and in fact, makes imperative a more exact control of the processes of manufacture such as the checking of purity of materials, correctness of firing temperatures, etc. Second, it permits a more exact fitting of the formulae to the available materials to obtain the best results.

R. P. JACKSON

Electrical Porcelain

G. I. Gilchrest and T. A. Klinefelter

This article deals with a phase of the electrical field which is still in the "rule of thumb" stage in a great many respects. A resumè of existing literature on the subject shows data of varying value, and much haziness in general. The electrical porcelain manufacturer, the ceramic engineer, the designing engineer and the operating engineer all view the problem from different angles. The object of this article is to bring about a better understanding between production and operating engineers, particularly that the latter may understand the manufacturing standpoint. To get this standpoint clearly, it is desirable, first of all, to outline the manufacture of electrical porcelain step by step; next, the data obtained from an investigation of porcelain mixes and ingredients and their influence on design; finally, the design itself.

THE foundation of porcelain manufacture is the mixture of materials which, when burned, makes the porcelain. Electrical porcelain, as far as its main ingredients are concerned, is like other porcelain, china ware or chemical ware. The proportions are different and the treatment a little different.

A mere listing of the various components of the high grade wares and the widely different localities from which they come will enable one to understand how the porcelain maker is hampered by variable factors.

SELECTION OF MATERIALS

The three main factors, or ingredients, are flint, feldspar and clay, and there are many different kinds of each ingredient to choose from. In the choice of flint, there is flint from the pebble, which is an amorphous form; flint from quartzite, the crystalline form, or just plain, pure sand, ground up. And then, again, it may be dry ground or wet ground. There are numerous feldspars, and a great variety of clays.

In the case of flint the porcelain maker wants a finely ground or powdered material which is clean and pure. The ordinary flint is very finely ground quartz rock, almost pure silicon dioxide. In appearance, the ground material might be mistaken for ordinary white flour. As the material is abundant, there is no trouble from adulterants or impurities, and so the user is generally concerned only about the fineness of its grinding. This is important, so a shipment of flint is usually checked up for fineness of grain and moisture content.

The same statement applies also to feldspar shipments so far as the usual routine testing is concerned. However, due to its importance and the wide variation of feldspar quality, other tests must be made, and the material checked from time to time. The feldspar is the active agent in the mix during the burn, and, if adulterated with flint or with an inferior feldspar, an otherwise high grade spar may be very inefficient in producing the degree of vitrification desired. So a chemical analysis is frequently of service in determining the quality of the material. A much used test is to melt some of the feldspar in the kiln and obtain an idea as to its quality by examination after the burn.

A still better method, which was used during the investigations here described, is to make the feldspar into standard cones, such as are used in determining kiln temperatures. These cones are made from the same materials as the body itself, but of such proportions that they flux or deform when the proper firing temperature is reached. Standard set of cones of standard composition are made in pyramidal form and are set in a base or plaque of clay as shown in Fig. 1. The temperature is indicated by the degree of deformation, which is a measure of both the duration and intensity of the heat. In order to determine the properties of a new feldspar, cones of the pure spar are made up, also some containing varying amounts of flint; all are placed together in a base or plaque with regular standard cones and fired in the kiln. By comparing these cones with those made from other feldspars the relative value of the feldspar in the body mix can be judged quite accurately.

As to their chemical natures and properties, feldspars are alkaline aluminum-silicates, and so are rich in either soda or potash or both. But there is no practical

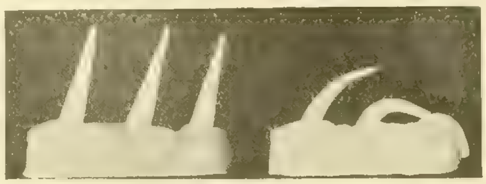

FIG. 1—STANDARD PYRAMIDAL TEMPERATURE CONE PLAQUES
Shown before firing on the left and after firing on the right.

commercial process for making the proper separation. If the chemist can find the key, he will unlock a wonderful storehouse of these valued products, especially the potash. Furthermore, it has been found that the potash feldspars are the more highly desirable in the manufacture of high grade clay wares, rather than the soda spars, since the potash ware has a clear bell-like ring when struck, while the ware made of the soda spar gives off a dull wooden sound.

In the same way, the variation of clays is wide. No two clays are quite alike. However, in a broad general way, the porcelain maker divides his clays into two classes—china clays or kaolins, and ball clays. In both cases he has an enormous variety from which to choose.

When feldspar, under the action of water, breaks up it forms clay. Thus, clays are simply products of decomposed or weathered feldspars. If the feldspar is pure and free from coloring oxides a white kaolin, rather coarse grained, is the result: If, however, the feldspar or kaolin has been washed away and mixed with iron, etc., the various colored clays are the result. If the process of washing and grinding is continued a long enough time, a very fine grained clay is the result. In its journey, it has become thoroughly mixed with

organic materials. Such clays become our ball clays.

The china clay, coarser grained and freer from impurities, burns to a whiter color than the ball clay, does not vitrify or fuse as soon, and gives, consequently, a body of rougher texture. Mostly because of the color, the china clay is given greater predominance in a body mix by the manufacturer of dishes, etc.

The ball clays, however, on account of their fineness of grain, and perhaps their organic substances, make a body which is very plastic and flows exceptionally well. Then, too, they are more sticky and hold the body ingredients together better than the china clay. Hence, a piece of ball clay ware, having been shaped and put aside, to dry is not so likely to crack. Having chosen feldspars from Canada or the New England States, or Pennsylvania or some southern state, and flint from sources as wide, and clay from England and Tennessee and Kentucky and Georgia or the Carolinas, the next step is a sampling of each carload received.

The amount of moisture or water must be determined, especially in the case of clays. The clays are likely to contain a 20 percent variation of moisture content. In the case of the other materials, flint and feldspar, another factor must be watched carefully. This is the determination of how finely the material has been ground in the mills.

MECHANICAL TREATMENT OF MIX

The batches are usually weighed in lots of about one ton. Since they are sticky and hard to break up, the clays are weighed first and thrown into the "blunger" some time before the remaining ingredients are added. The blungers are great churns which beat and mix all the ingredients with hot water, so that after several hours of blunging, the mass is reduced to a thick, creamy consistency termed "slip". The hot water tends to keep the temperature the same summer and winter. Of course, for the sake of adequate production, several of these blungers are going at the same time. Having been blunged, the slip from several blungers is run together and mixed and allowed to run over a screen which is kept shaking rapidly by mechanical means. The screen catches most of the dirt and impurities and coarsely ground materials. The slip which runs through the screen goes on to a cistern where it is kept in motion to prevent the heavier ingredients, the flint and feldspar, from settling out.

From the cistern the slip is pumped up into filter presses. The water is strained out to a certain degree, leaving a cake behind containing a more or less definite water content. The time required to do the pumping, and the pressure to which it is necessary to pump, depend primarily upon the body mix. Commercially the pumping takes several hours for electrical porcelain.

After the pumping is completed the cakes are taken to a cellar or storeroom where they are piled up in a close compact mass. Here the mass stands and ages for considerable length of time. This aging is primarily for the purpose of allowing the water to permeate all parts of the mass equally and thoroughly. The aging time varies considerably in practice and depends upon the mixture itself, the kind of cellar used and the ultimate process of manufacture. For instance it has been found that clay stored on oak planks becomes more plastic than when stored on a cement floor. The tannic acid of the oak is supposed to be the main factor here.

Instances of this kind have led to considerable experimenting with the use of chemicals for adding plasticity to clay. Although the experiments were rather successful, on the whole the results have never been adopted commercially because in most cases it is considered cheaper to buy a clay of the necessary plasticity rather than to treat an inferior grade. The introduction of some acid does not explain all of this phenomenon of added plasticity due to storing, and in some cases investigators have proven that a certain amount of bacterial growth goes on. However, the ordinary commercial mix cannot wait on bacterial growth nor bother with chemical treatment. It is aged long enough for the moisture content to become uniform.

Having reached this stage, the mass is now intimately and thoroughly mixed by machines to obtain

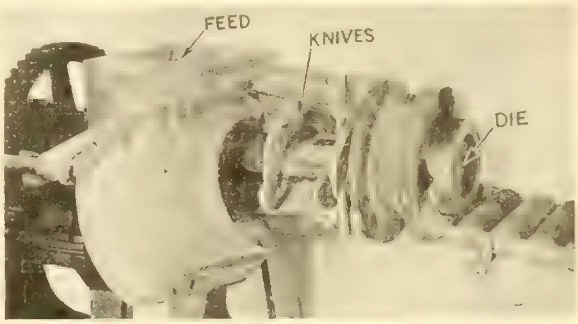

FIG. 2—HORIZONTAL PUG MILL.
Cover removed to show position of knives.

the maximum degree of plasticity and workableness as well as to eliminate as much as possible, the air in the clay. There are various sorts of machines for doing this, the commonest one being the "pug" mill. This is a tube or cylinder, horizontal or vertical, with a central shaft carrying knives. These knives, set at proper angles, cut and push the clay toward the end, as shown in Fig. 2, where a relatively small hole allows the mixed clay to come out. The setting of the knives and the speed at which they travel are determined primarily by the kind of body used. The hole for allowing the escape of the clay, is threaded so as to allow a die to be screwed on, so that the opening may be varied in size or shape. Its construction is of great importance.

A clay column flows in much the same manner as water in a stream—the center faster than the sides. In bad cases, this differential flow causes layer after layer which at times can be unwrapped almost like a roll of cotton batting. A die nozzle and an extruded clay section two inches wide by three-fourth inch thick are shown in Fig. 3. The part separated from the die was cut flush with its face. The section protruding from the nozzle illustrates the manner in which the friction

of the sides causes the conditions above mentioned. The knives evidently start some of this trouble, especially where the clay is quite plastic and does not weld together again very readily after being cut.

Although this trouble is always reduced as much as possible, it is never absolutely eliminated with this type of machine. In the old method of working the clay by hand, termed wedging, this difficulty was not present

FIG. 3—DIE NOZZLE AND EXTRUDED CLAY SECTION
Part of pug mill shown in Fig. 2.

but it is, of course, much too slow and expensive a method to be used commercially. However, if the die is properly constructed, the knives carefully set and the speed properly adjusted for a particular body mix, there should be little trouble from laminations. Furthermore, the workmen rework the clay to a certain extent so that any lamination will be neutralized almost entirely.

FORMING THE WARE.

In working the body into ware, it goes to the various benches, to be "jiggered" or pressed, or turned on a lathe. All these processes are really mechanical modifications of the ancient method of making clay ware by "throwing"; which consisted in placing a lump of clay at the centre of a horizontal wheel, which is kept spinning. The article is then pulled up and shaped by hand.

To insure uniformity and gain speed, the jigger wheel came into use. Instead of a flat horizontal wheel, a pot-shaped container is used, which holds a plaster mold. This is shaped on the inside in the form of the outer surface of the piece to be manufactured. The inside of the piece is then shaped by a cutting edge or form which swings down in the arc of a circle or drops down like a drill press. A jigger arm is shown in two positions in Figs. 4 and 5. A modification of this method is the jigger press where the mold is held stationary, and the inside of the clay piece is shaped by a core or plunger which does the spinning as it drops down. The plunger must be kept heated to the right temperature or the clay will stick to it. In neither case is the operation quite as simple as it looks. The chunk of clay from which the ware is formed must be shaped by hand and worked somewhat before dropping into the mold and, furthermore, it must be dropped in rather carefully. The jiggered ware must be manipulated and smoothed by the workman while it is being shaped.

After being formed the mold and shaped ware are allowed to stand for several hours in order to stiffen. This is accomplished by the mold, which being of plaster of Paris absorbs water from the ware. The ware is then taken from the mold. The making of molds is one of the important processes in a porcelain plant. The molds are costly to model and break quite easily. The design of the ware must also be such that it can be removed from the mold, which is in one piece.

After remaining in the molds a sufficient time to permit handling, it is in a condition known to potters as "leatherhard", when it is delivered to the trimmer, who places it on a plaster shape which is the reverse of that in which it was formed. The plaster die fits the inside of the ware, leaving the outside exposed. The whole is set in a revolving container, and the trimmer smooths and finishes off the outer surface. Being relatively smooth on the inside and outside the ware can now be dried. In many cases, this procedure is reversed, i. e., the ware is dried to a condition termed bone dry and then trimmed. Both methods have their advantages and disadvantages.

Certain types of electrical porcelain, such as bushings and bus-bar supports, are quite difficult to handle by jiggering. In such cases, a cylinder of clay of correct size is squeezed from the pug mill and allowed to dry to a stage just right for turning. It is then placed on a mandrel and turned down like a piece of wood. It is easy to see that if the blanks are not properly pugged, dried and handled, they may turn out defective.

FIGS. 4 and 5—SIMPLE JIGGER ARM
Used to form or press the clay into ware. A finished cup is shown in Fig. 4.

Another process of recent origin is that of casting. This consists in taking the clay after it has been filter pressed and working it back again into the form of a slip by the aid of chemical salts. Using these, it is pos-

sible to obtain a clay slip which will pour in a fine stream and yet possess little more water than the clay being used at the jigger wheel. In this condition the slip may be poured into molds constructed for the purpose and form all sorts of intricate shapes not possible by other methods. This method requires careful technical control and has not yet displaced the ordinary methods when they can be used. It is quite largely used in art ware, however, and results in exquisite work.

The last process in common use is that of dry pressing. Here the filter cake is dried out, beaten up into small pieces, a definite amount of water added and further disintegrated into a fine powder. It is then placed in powerful presses and squeezed between dies. This results in a compact mass which becomes quite tough on being dried out. The ware produced by this method is somewhat different in structure from that produced by the other methods, which are known as the wet process and the casting process. It is more open and porous as a rule. In general, it is used for low voltage porcelain; that is, knobs, cleats, switch bases, etc. After being formed, the drying, trimming, etc. is carried on in the same way as the other processes.

DRYING

The drying of clay is a step in the process of manufacture, next in importance to that of firing. The general weather conditions, drafts in the drying room, rapid change of humidity, rate of heating, and design of the ware are several important factors. The designer must be eternally on the lookout in the matter of so shaping his piece that the drying can be carried out on a commercial basis. Depending upon the design, the ware may be dried in a few days or it may take weeks. Since the drying of any piece of ware, is a matter of several days, the drying areas occupy a large proportion of the factory, and the space must have a fair margin over the normal demand, so as to keep a steady production.

GLAZING

When dried, the ware is dipped in the glaze. This is a thin coat of glass made up of the same ingredients as the body, in different proportions and with materials added which will cause the mixture to melt to a glass long before the body itself. Generally a coloring oxide is added to produce the desired color. Its uses are several. The body surface of the unglazed piece is slightly rough and would collect dirt. The glaze prevents this. Again, the color can be varied. Generally, the color is such as to render it inconspicuous. The extra insulation afforded by the glaze is too small to be taken into account. The glaze must be kept stirred constantly, must be of the right weight, must be put on to the proper thickness, and finally, must be fired correctly. Unless the glaze is suitable to the particular body on cooling it may contract more than the body and pull apart in cracks, generally called crazing. Old glazes nearly all craze in time. Just as often the reverse of crazing, known as "creeping" or "crawling", occurs and the glaze collects in globules, or draws away from an edge, leaving the body bare in places. Again unless the proper degree of heat has been reached, it will look dull and pitted, and if overheated, the color may change or even be burned out. The colored glazes are rather limited, since very few coloring oxides will withstand the high heat of the porcelain kiln. Two or three are reliable and one or two more rather uncertain. The rest simply evaporate. Fortunately color, especially delicate shades, is unimportant and rather a minor consideration in electrical porcelain.

BURNING

After glazing, the ware is ready for the kiln. Here the pieces are placed in "saggers", or refractory containers which hold the ware. The saggers are stacked one on top of another, until the kiln is filled.

A number of physical and chemical changes take place in the firing of porcelain. There is still a certain amount of water held mechanically in the ware. This is first baked out. During this period, the rate of heating must be slow; otherwise, the water quickly turns to steam and blows the ware to pieces. The next thing to escape is water in chemical combination. As the temperature continues to rise, various gases are given off by the glaze constituents. It is only after these gases are driven off that the glaze becomes smooth.

Finally, the white hot stage is entered. The feldspar grains soften and fuse with the flint and clay. The flint grains partly dissolve as well as most of the clay particles, the feldspar acting as the flux or solvent. The feldspar becomes molten and the clay particles break up into other chemical forms, parts of which are dissolved in the feldspar. Since the burn is not carried to a high enough temperature for the flint to dissolve completely in the feldspar, the body tends to remain more open and porous the higher the flint content. With still higher temperatures, entirely different characteristics might result, due to the continued solution of ingredients and change of chemical form. The burning having reached the necessary high temperature, the kiln is allowed to cool slowly. Rapid cooling would spoil the ware, since internal strains would be set up, resulting in cracks after being taken from the kiln. After drawing from the kiln, the ware is ready for inspection. No glaze defects, no cracks in the body, no over-fired nor underfired ware is tested or assembled. Before assembling, the separate parts are tested electrically, and after assembling the whole piece is tested. It is then ready for shipment.

The New Passenger Locomotives

Of the Chicago, Milwaukee & St. Paul Railway

W. R. Stinemetz
Heavy Traction Division,
Westinghouse Electric & Mfg. Company

THE ten passenger engines which the Westinghouse Company is building for operation on the electrified section of the Chicago, Milwaukee & St. Paul Railway embody many novel features not existing in the present engines. They are the most powerful locomotives in passenger service, a single locomotive having capacity sufficient to haul a 950-ton train (12 coaches) over the entire mountain section at the same speeds as called for by the present schedules. The rating is 4000 horse-power for one hour, or 3200 horse-power in continuous operation, with a starting tractive effort of 112 000 pounds. The speed on level track will be about 56 miles per hour and about 25 miles per hour on the two percent grades.

One interesting characteristic which is desirable in passenger service, but which has not heretofore been attained with this type of electric locomotive, except at the expense of heavy rheostatic losses, is flexibility of running speeds.

Speed Regulation—These engines have nine running positions without rheostatic loss, ranging from 8 to 56 miles per hour, depending on the load. This feature affords greater flexibility in the manipulation of the train and is of value in governing the power load of the system during peak load conditions. It is accomplished by using six 1500 volt twin motors on the locomotive, arranged for three-speed combinations consisting of,—

Position 1—One set of six motors in series.
Position 2—Two sets of three motors in series.
Position 3—Three sets of two motors in series.

These combinations give one-third, two-thirds and full speed.

Two additional running speeds are obtained on each speed combination by means of inductive shunts on the main motor fields. This cuts down the current peaks, saves rheostatic losses and enables the power demand over varying profiles to be kept more nearly constant.

Twin Motors—The use of twin motors, as shown in Fig. 4, with quill drive, not only permits the most effective use of the space between the driving wheels, but also the use of two armatures, each wound for 750 volts and geared to the same quill, thereby obtaining the advantage of better commutating characteristics inherent with low voltage motors.

Low-Voltage Auxiliaries—The complication and hazard of high-voltage apparatus is minimized on these locomotives by the use of low-voltage auxiliaries. The motor of the motor-generator set used for train lighting and charging the storage battery is the only high-voltage apparatus among the auxiliaries. The resultant simplification secured by the use of low-voltage appliances decreases the complications of installation, maintenance and operation. Ordinary inspection can be carried on, including the functioning of all switches and auxiliaries, with complete absence of 3000 volt power inside the locomotive.

Regeneration—The use of regenerative control for holding trains when descending grades is such an important function in these locomotives that special arrangements have been perfected to secure positive operation of this feature over widely varying speeds. The same main motor combinations for motoring are used for regenerating except that the fields of the main motors are separately excited over a wide range by axle-driven generators. These are so connected with balancing resistances, that inherent stability in the motor characteristics during regeneration is assured, irrespective of whether the changes in line voltage are sudden or gradual.

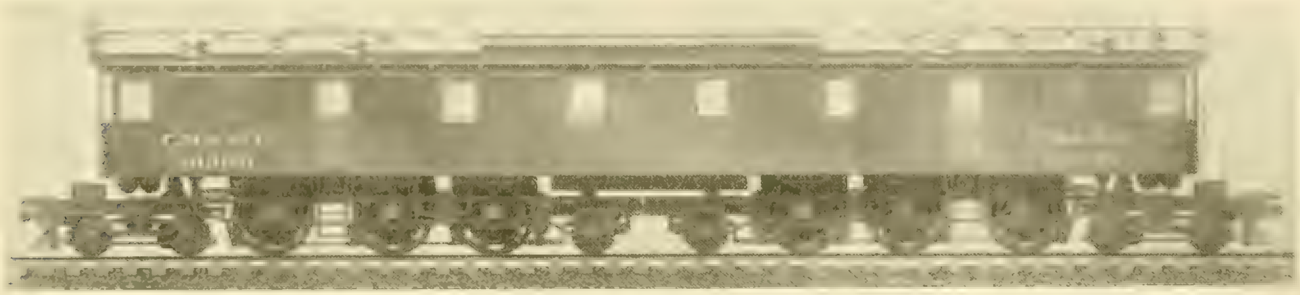

FIG. 1—THE NEW 4000 HP PASSENGER LOCOMOTIVE OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

Axle-Driven Generators—While the regenerative braking of trains lessens the duty on the air-brake equipment, further safety in braking with electric engines is introduced with the axle driven generators. These machines are mounted on the inside axles of the guiding trucks of the locomotive and, in addition to exciting the motors during regeneration, furnish the power for operating the air compressors and blower motors when the locomotive is hauling. This method insures a current supply to the air compressor motors irrespective of the overhead trolley supply, and the train can be taken down the heavy grades under control with power off the line.

Train Heating—Heat must be assured under any conditions of failure of other equipment or delays to trains. The heating plant therefore, is entirely independent of the electrification, each locomotive being equipped with an oil-fired boiler, designed to burn crude oil. Provision is made for a storage of 3600 gallons of water and 750 gallons of oil in each engine.

Center of Gravity—The center of gravity of the main running gear, including motors, will be 41.5 inches above the rails and the height of the center of gravity of the complete locomotive will be 63 inches above the rail, while the non-spring supported weight on any single driving wheel will be that of wheels, axles and driving boxes only.

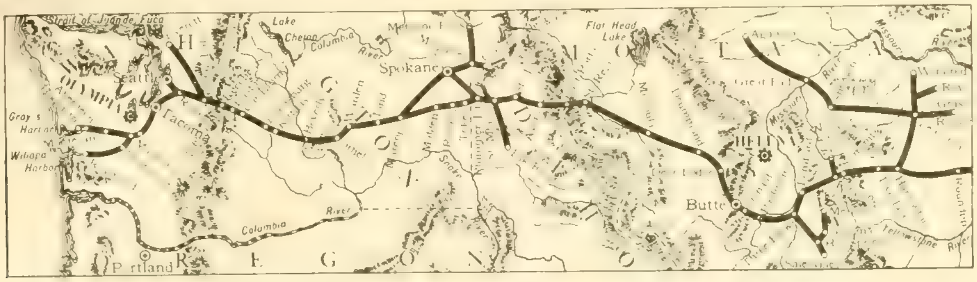

FIG. 2 THE ELECTRIFIED SECTIONS OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

MECHANICAL FEATURES

Cab and Running Gear—One of the most noticeable features of the new locomotive is the concentration of all the auxiliary and control apparatus in a single cab. This emphasizes the modern tendency in design toward the conservation of weight and space for a maximum output of power. The cab is carried on two main running gears, each having a four-wheel guiding truck, three driving axles in a 16 ft. 9 in. rigid wheel base, and a two-wheel trailing truck. It thus corresponds to two Pacific type running gears coupled together and having two-wheel trucks on the adjacent ends.

The main running gear center pins are located midway between the first and second driving axles of each running gear. On one running gear the center pin is

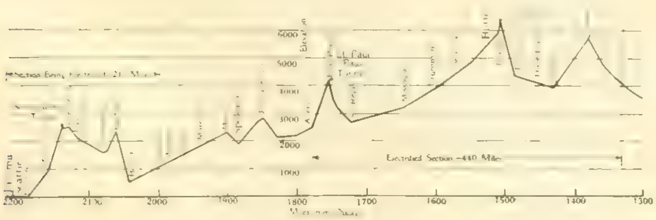

FIG. 3—PROFILE FROM HARLOWTON, MONTANA TO THE COAST

designed to restrain the cab both longitudinally and laterally, while on the other running gear the center pin restrains the cab only in the lateral direction, permitting free relative longitudinal movement. This arrangement of rigid and floating pins relieves the cab of all pulling and bumping strains, due to the train load, as these are taken directly through the running gear side frames and bumpers.

The driving wheels are 68 inches in diameter and carry 55 000 pounds per axle. The guiding trucks have 36 inch wheels and the two-wheel trucks each have a load of 39 000 pounds at the rail, with approximately 62 000 pounds distributed on each of the four-wheel trucks. The complete locomotive with a total length over coupling of 90 feet will weigh, ready for service, 266 tons, with an adhesive weight of 330 000 pounds.

Flexible Drive—The quill drive affords a means for permitting a motor located well above the road bed to drive an axle which, with its wheels, is free to follow the rail independently. It is evident that this drive secures all the advantages of a flexible gear in cushioning the transmittal of torque and avoids the road shock far more effectively than with the common flexible gear construction and mounting.

Equalization—Each main running gear is arranged with a three-point equalization with the single point toward the end of the locomotive, in accordance with accepted steam locomotive practice. The four-wheel guiding truck center pin and cross equalized leading pair of driving wheels are equalized together on the longitudinal center line of the locomotive. This arrangement combines all the advantages of the standard front end construction of the "American" and "Consolidation" types of steam locomotives. The two remaining pairs of driving wheels and the two trailing wheels of the main running gear are side equalized together again, following accepted steam locomotive practice.

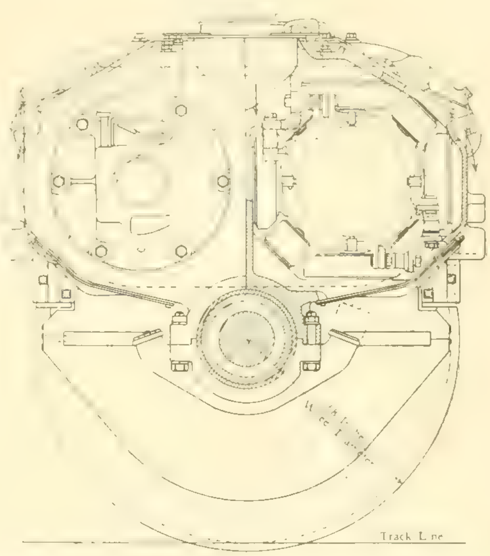

FIG. 4—CROSS-SECTION OF A TWIN MOTOR WITH QUILL DRIVE

A point of interest in electric locomotives, without connected wheels, is the result of weight transfer due to tractive effort. This is caused by the drawbar pull being exerted at the coupler height which, with the reaction at the rail, tends to lift the leading end and depress the trailing end. This changes the weight distribution and increases the tendency to slip. The method of equalization described reduces the weight variation on the driving wheels to only six percent from normal when pulling at thirty percent adhesion. The careful attention given to the details of design and operation insures that these new engines will mark an epoch in the advancement of the design of electric locomotives for steam railroad passenger service.

Factors that Determine Maximum Rating

Of a Direct-Current Machine for a Given Speed

F. T. Hague

THERE are two principal limitations to the output of direct-current machines, depending upon whether the limitation is first reached in heating or in commutating capacity. For continuously rated machines, this classification is usually determined on the basis of speed; low-speed machines being invariably limited in continuous capacity by heating, while high-speed machines usually find their limitation in commutating capacity. In this latter class are high-speed motor and reduction-gear-driven generators, high-speed, low-voltage electrolytic generators, and similar machines. Machines adapted to abnormal duty cycles of high peak and continuous load capacity have their limitations fixed by the relative magnitude of these two factors. Reversing rolling mill motors represent a type requiring extreme peak load capacities, and they are usually rated in terms of their peak load capacities, as fixed by commutation limits, the temperature limitation being usually well above the required continuous capacity. Non-reversing units may have relatively lower peak loads and higher continuous loads, so that heating may gradually become the predominating limitation in this case. The dividing line in these types of machines is usually disassociated from speed conditions, and fixed by load and service conditions.

Even though the output of high-speed machines may be limited by commutation, this does not necessarily imply that they are rated with less margin of safety than lower-speed machines, although this margin may be of a different character. High-speed machines have the advantage of the most favorable electric and magnetic design proportions, the best grades of materials and the most accurate adjustments. Direct-current machines are built to commutate satisfactorily at definite maximum ratings, which are the bases of guarantees. The relation of this maximum rating to the normal load rating is different for different types of service, and is a partial measure of a machine's margin in operation. For instance, gear-driven sets carry 25 percent overload for two hours, motor-driven sets 50 percent for two hours, railway type generators carry from 100 to 200 percent overload for a few minutes, while mill motors carry peaks of four to six times full-load at definite short intervals. When it is stated that a machine's output is limited by commutation, it is evident that this limitation is first encountered at its maximum loads, and may be practically no indication of the machine's ability to carry its normal load with satisfactory commutation. Any high-speed machine, regardless of all other meritorious features it may possess, must have its rating determined by its ability to commutate successfully. High efficiency, low temperature rise, and low first cost, are important factors but they cannot outweigh bad operation at the commutator.

Since commutator operation must be a criterion of rating of large high-speed machines, any method of determining the maximum capacity, which it is possible to build at any given speed, must be predicated upon certain assumed design and operating limitations. These limitations are fixed by commutating conditions, and are true limitations only to the extent that they are fixed in conformity with the experience acquired through the building, testing and operation of many machines in various classes of service over a long period of years. Improvements in mechanical and electrical designs, development of new manufacturing processes, improvements in grades of materials, etc., are vital factors, constantly tending toward the extension of these various limitations, so that they are not permanently fixed. Thus some of the limitations in present practice differ radically from those of ten years ago, and it is to be expected that, as improvements demonstrate their efficiency and become incorporated in designs (as commutating poles have done in all classes of power machines, and as compensating pole face windings are doing in certain special lines of machines), still further and perhaps more radical improvements and extensions will be made.

An evident condition is that any one arbitrary set of limitations cannot be equally applicable to all high-speed machines of various voltage classes and different service applications. In each particular voltage class, and in each type of service application, there are a few special limitations which are of fundamental importance. For instance, in 250 volt machines, flashing practically takes care of itself, and the principal problems are commutation, brush rigging and mechanical commutator design suitable for handling the large currents involved. In the 600 volt class machines, all design limitations are met under favorable conditions and there is no one all important limitation. This favorable condition permits the building of the largest possi-

ble ratings at any given speed on machines of this voltage class. High-voltage machines of 1200 to 1500 volts for railway service must be constructed primarily to minimize the possibility of flashing and resultant damage, and at the same time have the abnormally large overload capacities required for this class of service. Reversing mill motors must carry the peak currents necessary to produce the maximum motor torques required, and their limitations are concerned with the commutation of peak loads of rapidly changing magnitude and the mechanical limitations incident to sudden acceleration and retardation incidental to reversing service.

Any analysis of the factors which limit capacity must necessarily be based upon up-to-date types of approved constructions, both mechanical and electrical. For instance, no large capacity, high-speed design would be considered that does not employ commutating poles. Compensating pole face windings have amply proven their necessity on certain classes of machines, such as high-voltage railway generators, large reversing mill motors, etc. The type of armature winding employed very materially affects the commutation limits, particularly on low and medium voltage machines of about 250 volts, such as are used in electrolytic work and for the supply of small power motors in steel mills. Large capacity generators practically without exception employ multiple windings having one turn per commutator bar. It is known that types of windings having the equivalent of one-half turn per commutator bar will very greatly extend commutation limits. Any type of winding which will double the number of commutator bars in an ordinary multiple winding, without increasing the number of series conductors, would correspondingly allow the number of series conductors to be reduced 50 percent and still satisfy flashing conditions. As commutation is improved directly as the series conductors per pole are decreased such a type of winding would evidently very materially extend some of the generally accepted commutating limitations of low-voltage machines, and permit higher outputs and higher speeds. Such windings have, up to the present, been uncommercial, solely because of excessive cost of manufacture. The improvements possible with these types must necessarily be left for future developments.

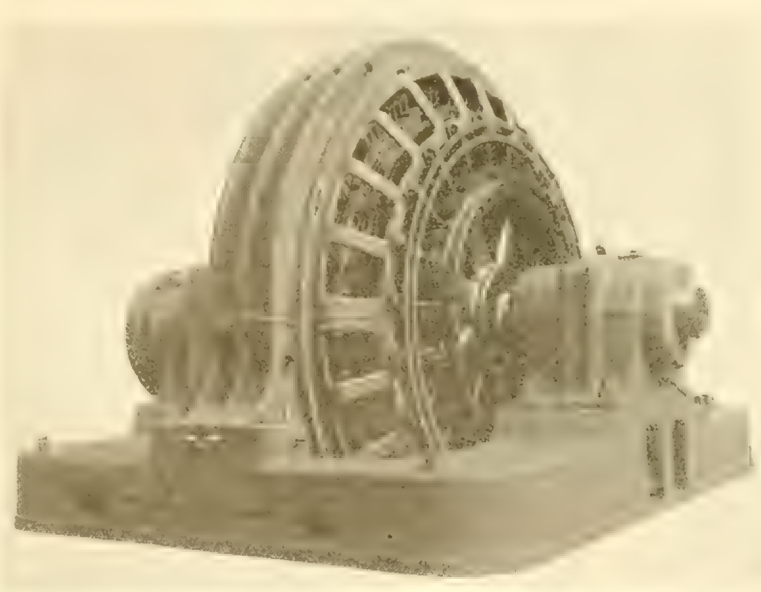

Fig. 1—Photo. of [illegible] Reversing Blooming Mill Motor

In a similar manner, only types of mechanical construction need be considered which are recognized as standard. Fortunately, the mechanical construction of the major parts of high-speed machines bear considerable resemblance, and it is only in commutator design that there has been any great divergence in methods of construction. This condition is brought about by the fact that commutator mechanical construction has been a positive limitation of output in both low and high-voltage machines. In low-voltage machines, the permissible commutator length practically fixes a machine's cost, while on high-voltage machines the maximum commutator diameter and peripheral speed are direct limitations of the maximum voltage and output.

COMMUTATOR CONSTRUCTION

Three general types of construction have been developed for the building of high-speed commutators of the unusual face length required for low-voltage machines. The face length of a commutator is limited by its peripheral speed and the longer the face length the more difficult it is to keep true. The permissible face length, as limited by mechanical constructions, has been gradually increasing as such constructions have been improved, and still further improvement is logically to be expected. When it is considered that the deflection of a commutator bar increases very disproportionately as the face length is increased, it is evident that there is a definite mechanical limitation to its length. Practically all commutators which do not involve unusual design features, employ the standard two V-ring method of support, because it permits adjustment and tightening as the commutator bars take their final set under actual operating conditions. Another point of equal importance is the facility with which repairs may be made with the V ring type.

Commutators of the length required for low-voltage machines may be provided for by the addition of an auxiliary supporting V-ring having separate means of adjustment and tightening. This three V-ring type of construction embodies all the advantages of the standard two V-type, and is not materially more expensive, because of the saving in materials which it effects. The question of whether a commutator should be built with two or three V-rings depends entirely upon which method of construction will be more economical for the building of an equally good commutator. Usually with peripheral speeds around 4000 feet per minute face lengths up to 24 inches are possible with the two-V

method of construction. Beyond these limits, the three-V type becomes necessary.

European practice, where exceptional commutator face lengths are required, has favored the use of two or three independent commutators mounted side by side, and working in parallel. This practice has not gained favor in this country because commutator mechanical conditions may be amply provided for by our present methods and because with two or three commutators side by side the division of load between them is affected by surface conditions and the inside V-rings are inaccessible for repairing and tightening.

The shrink ring method of construction has been practically the only satisfactory method of support for the commutators of small machines which run at turbine speeds. It has certain theoretical advantages on excessively high-speed commutators, because of the space position occupied by the supporting rings, but when applied to long commutator machines, it necessarily increases their face length. Among the chief objections to this type of construction are the absence of suitable means of adjustment or tightening as the commutator ages, and the lack of any provisions for making repairs short of disassembling the commutator.

As regards operation, the higher the commutator speed, the more difficult it is to maintain good contact between the brushes and the commutator face. This is not merely a function of speed, but rather of commutator diameter and speed combined. Apparently, it is easier to maintain good brush contact at 5000 feet per minute with a commutator 50 inches in diameter than with one of ten inches in diameter. Very slight irregularities of the commutator surface will cause the brushes to jump at high peripheral speeds and the larger the commutator diameter with a given peripheral speed, the less is this tendency. Good practice in the last few years has considered that commutator peripheral speeds of 5000 to 6000 feet per minute are sufficiently high to meet present day requirements.

MAXIMUM VOLTAGES

The maximum voltage for which a single direct-current machine may be built, at any given speed, is fixed by the space available for commutator bars between brush arms. The commutator space available is directly dependent upon the commutator diameter selected, and this in turn is limited both electrically and mechanically by the conditions governing peripheral speed. The peripheral speed of any commutator in feet per minute may be expressed as the distance in feet between brush arms, multiplied by 120 times the armature frequency in cycles per second. In other words, a 25-cycle armature can have 2.4 times as great distance between brush arms, for a given peripheral speed, as a 60-cycle armature. From these conditions, the maximum voltage for which a single machine may be built is inversely proportional to its armature frequency. For a given speed, high-voltage machines must necessarily have fewer poles than moderate voltage machines, in order to obtain the necessary brush arm spacing, and this is the fundamental limitation which makes it impossible to incorporate as large a kilowatt capacity in a single high-voltage machine at a given speed, as in a moderate voltage machine. At the present time 1000 volts per single commutator is approximately the maximum which may be built without a material reduction

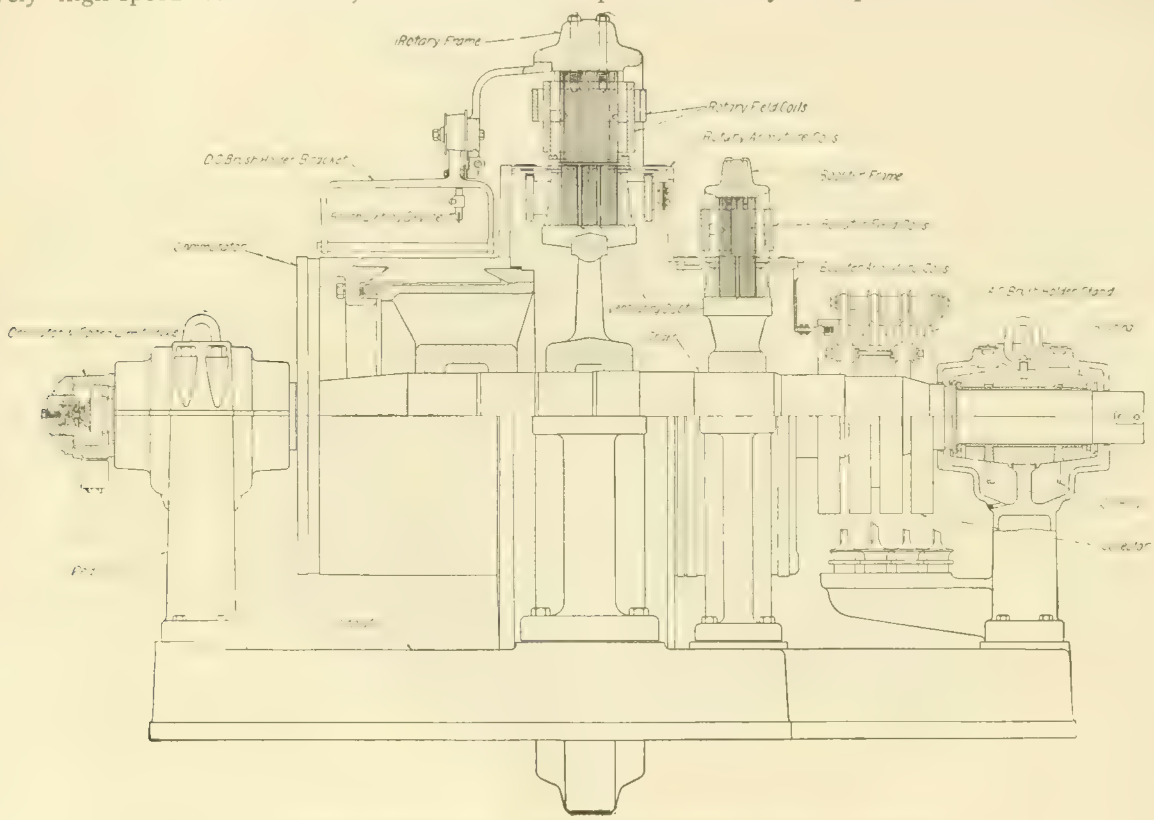

FIG. 2—CROSS SECTION OF A SYNCHRONOUS BOOSTER ROTARY CONVERTER

in the permissible kilowatt output at a given speed. For this reason, single units of greater than 1500 volts are practically never considered for any large capacity installation, it always being more satisfactory and economical to use two smaller capacity and higher speed machines in series.

VOLTAGE PER BAR

The permissible maximum voltage between brush arms is a criterion of flashing, and is limited by the maximum voltage between adjacent commutator bars, and by the permissible voltage per inch circumference of commutator. Under steady load conditions commutation is improved as the number of commutator bars per pole is reduced, or as the maximum voltage per bar is increased. This possibility of improvement in operation is the incentive for seeking types of constructions and types of windings which will permit reductions in the number of commutator bars required for a given voltage. On the other hand, the probability of flashing is largely increased if the maximum voltage per bar exceeds definite narrow limits for each class of machines. Line voltage exists across the commutator face between adjacent brush arms, and this voltage is split up into as many sections as there are commutator bars per pole, being distributed between these bars in proportion to the main field fluxes which the coils connected to them are cutting. The mechanical separation between adjacent bars is usually 30 to 40 mils, so it might be inferred from the sparking voltage required to jump this distance in air, that potentials of several hundred volts might be permissible between adjacent bars. However, experience has proven that voltages in the neighborhood of 30 volts are the maximum for large machines. In small machines, the voltage per bar may be considerably increased, because the higher resistance and reactance of a short-circuited coil tend to limit the voltage while maintaining the arc, and the short-circuit current will not rise to a damaging value. It appears that there is a critical relationship on large capacity machines between the maximum permissible voltage per bar and the minimum voltage which will maintain an arc in air.

Assuming a conservative maximum voltage between bars of 30 volts, and a field form distribution factor of 68 percent, the average voltage per commutator bar on a compensated machine should not exceed $30 \times 0.68 = 20$ volts per bar. For non-compensated machines, the field flux becomes distorted by load reactions, so that the maximum voltage per bar is liable to be increased as much as 30 percent under load conditions. For non-compensated machines, average voltages per bar of $20 \div 1.3 = 16$ is an approximate value which cannot safely be exceeded on large capacity machines, except where special precautions are taken.

While the maximum voltage per bar causes flashing, specifications almost invariably refer to the average voltage per bar; it is, therefore, important that the relationship between average and maximum be clearly understood. Compensated machines may have a higher average voltage per bar, but no higher maximum voltage per bar than non-compensated machines. Compensating windings, by eliminating load distortions except between compensating slots, allow the use of a higher field form distribution factor. These factors combine to allow compensated machines to have from 25 to 30 percent higher average voltage per commutator bar than non-compensated machines, and make the use of this type of machine imperative where unusual voltage and over-load conditions are encountered.

FLASHING

The likelihood of flashing in direct-current machines is fundamentally dependent upon the relationship between voltage and distance. An incipient arc between adjacent commutator bars may shoot out conducting copper vapor, bridging across a number of commutator bars having a high total difference of potential across them. For example, consider a high voltage machine where the commutator bars are as thin as mechanically possible, and the voltage between bars as high as is considered safe. Assuming a thickness of bar and mica of 0.20 inch, (5 bars per inch) and a maximum voltage per bar of 25 volts, there is a voltage of 125 volts per inch circumference of the commutator. In such a case, a small arc may result in a serious flash, due to the conducting vapor bridging a comparatively high voltage. Accordingly, when determining the permissible maximum voltage per bar, the voltage per inch circumference of the commutator must be taken into consideration. An average distance of one inch between brush arms measured along the commutator periphery may be assumed as a conservative limit for every 75 to 100 terminal volts, for high-voltage machines. However, difficulties from this cause have not yet become serious, possibly because no one has yet carried such constructions to the extreme in commercial work.

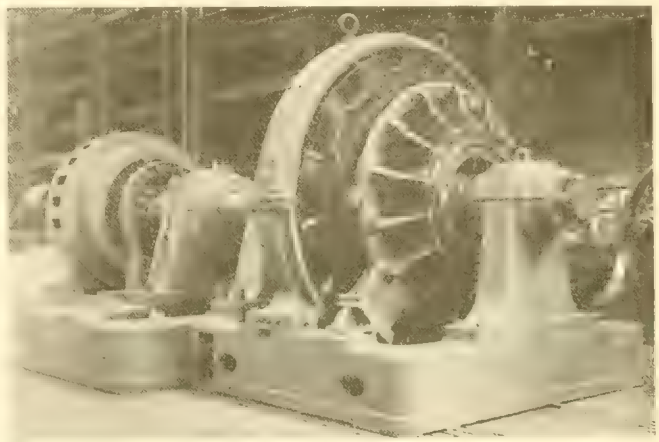

FIG. 3—FLY-WHEEL MOTOR-GENERATOR SET FOR REVERSING BLOOMING MILL

Supplying power to motor shown in Fig. 1.

MAXIMUM CURRENT

The maximum current for which a single direct-current machine of low voltage and kilowatts may be built, at a given speed, is generally fixed by cost considerations primarily and electrical limitations second-

arily. There is a demand for very low-voltage machines of abnormally high currents for electrolytic service, and the fact that they are never built in a single unit is, in itself, a proof that they are not commercial. The reasons for this condition are closely interwoven with some of the previously explained conditions. The maximum current of a machine is the product of the current per brush arm multiplied by the number of pairs of poles. Assuming a limiting current per brush arm, the maximum current output is limited by the permissible number of poles. On low-voltage machines, there is a minimum pole pitch below which a good commutating machine cannot be built, and this, in turn, requires that large current machines be built with abnormally large diameters, compared to the requirements of their rating, resulting in an unbalanced and very uneconomical machine. It usually turns out that where the total capacity involved is relatively small, two machines may be built more economically and with a greater margin of operating safety than one very large machine. Where the kilowatt capacity involved is

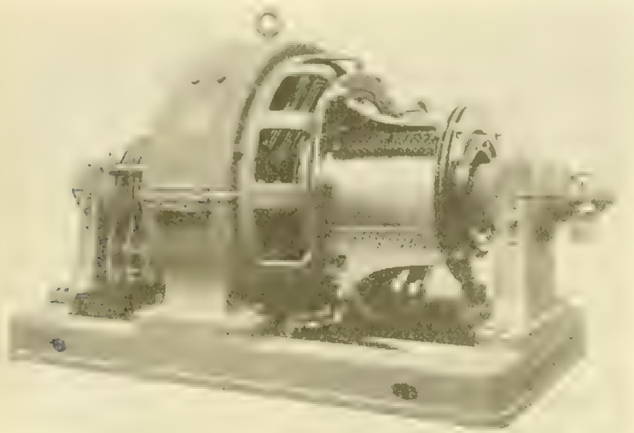

FIG. 4—750 KW, SIX-PHASE, 25 CYCLE, 250 VOLT, 750 R. P. M. ROTARY CONVERTER
Showing typical brush rigging construction.

large, as, for instance, with the water-wheel driven machines used for the precipitation of aluminum, the maximum current output for a given speed is not determined by economical conditions, but by electrical commutation limits.

There is a practical mechanical limit to the maximum current per brush arm, as fixed by the permissible current density in the brushes and the permissible length of commutator face. The maximum length being mechanically determined for any given case, the circumferential thickness of the brushes being fixed by the limits of the armature coil reactance voltage, and the current density in the brushes being fixed by limits of brush and commutator wear, it follows that the maximum current per brush arm must fall within well defined limits for the present methods of mechanical construction.

With very large currents per brush arm there may be difficulty in obtaining equal division of current among all of the various brushes per arm. The possibility of selective commutation is increased and, if this greater current per arm is obtained by the use of thicker brushes, rather than by greater length of commutator face, the result to some extent is equivalent to working a machine harder or nearer its limit. However, if the commutating conditions are such that a 1.25 in. brush has the same true current density as a 0.75 in. brush normally has, that is, the true density which includes all local currents and unbalancing of current between brush arms then, with equally well proportioned commutating poles, there should be no essential difference in operation between different widths of brush. Experience has amply proven the desirability of applying large size brushes in their logical field of application.

BRUSH WIDTH

The circumferential thickness of the brushes is fixed by the limits of the inherent short-circuit e.m.f. per brush, and the width of the commutating zone. On medium capacity, low-voltage machines, where commutating conditions are favorable, the permissible brush width is usually determined by the space available between the main poles in which those coils lie which are undergoing commutation. The danger in attempting to use too wide a brush and too wide a zone of commutation, is that the coils will approach too near the main field poles, while still under short-circuit by a brush, and have excessive voltages and local currents generated in them. Under average conditions, on low-voltage machines, the use of a wide brush is usually desirable, and it is common practice to find brushes 1.25 inches thick on machines of the 250 volt class.

It is generally the case in large capacity machines of moderate voltage that the number of bars which a brush may span, without having the sum of the inherent short-circuit e.m.f.'s add up to an excessive value, will determine the permissible brush width. In this case, the brush width depends largely upon the width of the individual commutator bars. Individual bars may be made wider only by increasing the commutator diameter and peripheral speed. Thus the brush width is dependent to some extent on the armature frequency for which the machine is built. In consequence of the wider bar width obtainable, fewer bars will be short-circuited on a low frequency machine than on a higher frequency one and in general, somewhat thicker brushes are permissible for given inherent short-circuit limits. This, in turn, allows more current per brush, so that the permissible current per brush arm generally increases as the machine voltage is decreased.

BRUSH CURRENT DENSITY

The permissible brush current density has an important bearing in determining the limiting current per brush arm. Brush densities on correctly proportioned machines may now be materially higher than the low densities found necessary on machines built before the advent of commutating poles. These higher densities are possible, because of the elimination of local currents. In commutating-pole machines, the current distribution at the brush face is nearly uniform under all

loads, but is not exactly uniform even in the best machines. Variations from uniformity, while possibly as much as 50 percent in good machines, are yet very small compared with the variations in some of the old non-commutating pole machines. In consequence, it has been possible to increase the apparent current densities in the brushes of modern machines considerably above former practice. In many of the old machines, an apparent density of 40 amperes per square inch at normal loads was considered high, while at the present time, with well proportioned commutating poles, 50 percent higher densities are not uncommon and the commutation is considerably improved. High-grade brushes with perfectly uniform distribution of current at the brush face can carry still higher currents without any impairment of the operating margin, so that the actual upper limit of brush capacity has not yet been attained.

DIVISION OF CURRENT BETWEEN BRUSHES

Unequal division of current between brushes on the same brush arm is to some extent influenced by the total current per arm. Where there are many brushes in parallel, and the total current is large, one brush may take excessive current, without materially decreasing the current carried by the other brushes. In the same way, the division of current among the brush arms of the same polarity is not always satisfactory. For instance, a variation of 25 percent between brush arms is not unusual, and a number of instances have been noted on satisfactorily operating machines, where the variation has been as much as 50 percent. Obviously, with such possible variations, it is not practicable to work brushes up to their maximum density, since some margin must be left for such possible unbalancing. Thorough cross-connection of brush arms by means of cross-connections of graded copper section and the use of cast-iron brushholder brackets of properly graded current-carrying sections have materially increased the limiting current per arm.

QUALITY OF BRUSHES

Brush quality has also kept pace in improvement with commutating conditions. Present grades of graphitic brushes suitable for use on undercut commutators are very materially better than older grades. This condition is particularly true of certain grades of imported brushes, although domestic grades of brushes have also shown marked improvement in quality. On the basis of one inch wide brushes and a current density of 50 to 60 amperes per square inch, a normal current of 1200 to 1500 amperes per brush arm is satisfactory on machines designed to carry 50 percent overload for short periods, such as two hours. Where commutating conditions permit the use of wider brushes, the current per brush arm may be correspondingly increased, without impairing the machine's operating margin.

ARMATURE REACTANCE VOLTAGE

When the limitation of output of a machine is due to commutation, the armature coil reactance voltage practically becomes the ultimate criterion of rating. The fundamental principle covering the relationship between commutation and reactance voltage may be briefly stated, as follows:— In the ordinary commutating machine, the armature winding, when carrying current, sets up local magnetic fields or fluxes across which the armature conductors cut during the commutating period, and thus generate e.m.f.'s, just as when they cut across the main field fluxes. These local fields, due to the armature current, have peak values at those points on the armature core where the coils which are being commutated lie. The coils which are thus short-circuited, have voltages generated in them, which the carbon brushes short-circuit. There is a certain short-circuit voltage per armature coil, for each value of current, which may be called the inherent short-circuit e.m.f. per bar, or briefly, the reactance voltage. This reactance voltage is the basic cause of sparking at the brushes. In general terms, it is proportional to,—

Kw × r.p.m. × Comm. bars [Pole pitch + Core length × Slot proportions]

From this it is evident that reactance voltage is directly proportional to the kilowatt output, and to the number of commutator bars per pole for a given speed.

FIG. 5—1000 KW, 600 VOLT, 900 R. P. M. MOTOR-GENERATOR SET

From his relationship, the general rule may be deduced that "The product of kw and r. p. m. is a constant on the basis of comparative commutation for machines of any given voltage or service class." Thus it is as feasible to build for 1250 kw at 900 r. p. m., as to build 3750 kw at 300 r. p. m. This relationship is frequently overlooked when considering the possibilities of various classes of machines for large outputs at high speeds.

NUMBER OF POLES

The number of poles has an influence on maximum capacity, because of its relation to reactance voltage. It is erroneous to assume that the difficulties of commutation increase directly as the number of poles is decreased on a given machine. This statement is only true where the change in poles increases the amperes per brush arm beyond a value for which a good mechanical design of commutator and brush rigging is practicable. Present methods of construction enable commutators to be built which are satisfactory mechanically for carrying large currents per brush arm, so that many 250 volt

machines are now built with the same number of poles as the same kilowatt machine would have on 600 volts. For example:—

Detail slot dimensions influence reactance voltage because parts of the armature coils are imbedded in slots. Wide shallow slots are recognized as favorable to commutation. However, slot dimensions must be determined by the current to be carried in the slot in conjunction with the permissible temperature rise. Average slot widths are usually limited to about five-eighths inch because of iron and pole face losses incident to too wide slots. On high frequency machines, deep slots are nearly always associated with high eddy current losses in the windings. The logical field for deep slots is in low-speed machines where commutating conditions are very favorable. As a rule, wide shallow slots favor good commutation, while deep slots tend toward economy and high efficiency, but are unfavorable to commutation, and may be the cause of excessive load losses if used at high speed.

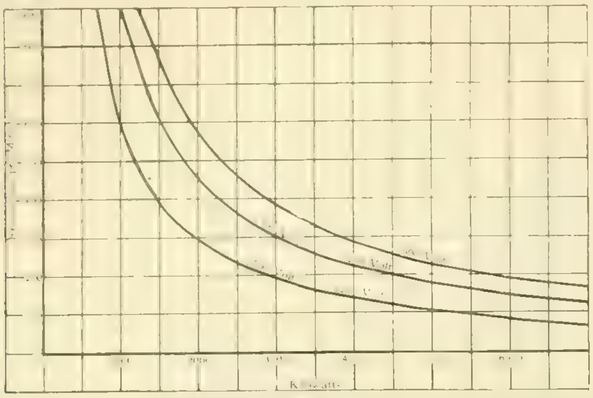

FIG. 6—LIMITING CAPACITY OF COMPENSATED DIRECT-CURRENT GENERATORS

KW RATING VS SPEED

To convey some approximate idea of the maximum normal ratings which are considered good practice at present, the curves in Fig. 6 are given to show the relation between kilowatts rating and speed. The basis on which these curves have been made up depends upon the setting of rather arbitrary limits, as previously stated. These are not fixed quantities, as each designer will set limits depending upon the experience he has had with the various classes of machines. The curves, however, show the general relationship between permissible outputs at the various conventional speeds and voltages. As these curves represent so-called limits, it is to be expected that most commercial machines will fall within them, and the extent to which a machine falls within these curves will represent in a measure the ease with which the machine may be designed and the margin which it may be expected to have in operation. It will be observed in these curves that the product of kw and r.p.m. is a constant for machines of each voltage class. The fundamental relationship embodied in these simple curves affords a reliable basis for considering the possible capacities at various speeds and voltages. They must necessarily show the handicaps of machine capacity which are present with both very high and very low voltage installations and emphasize the fact that machines of the moderate voltage class are most suited, from the economical standpoint, for high capacity installations.

Characteristics of Current Transformers on Open Circuit

W. R. WOODWARD

VOLTAGE or other constant potential transformers are operated with the primary winding in parallel with the power line and substantially constant voltage is thereby maintained on the secondary terminals. If the secondary terminals are connected together an excessively high current will flow in both the primary and secondary windings. A current transformer, on the other hand, is connected with its primary winding in series with the power line and if the secondary terminals be short-circuited the maximum current that can flow in the secondary is the current flowing in the power supply line multiplied by ratio of turns of the primary and secondary windings. If the secondary circuit becomes open circuited, the current flowing through the primary winding will cause the iron to become saturated, thereby producing very high voltage of peculiar wave form in the windings, which may injure the transformer.

The operation of a current transformer can best be explained by reference to a vector diagram. The current I_P in Fig. 1 is the current flowing in the power line and is determined by the load connected to that line and is in no way determined by the current transformer. The secondary current I_S is a function of I_P and the transformer ratio. In order to force the current I_S through the meter M and the resistance and impedance of the secondary winding and leads, a certain voltage must be developed in the secondary winding. In Fig. 2, E represents this voltage developed in the total secondary winding and ϕ represents the total flux in the magnetic circuit necessary to develop the voltage E. In order to produce this flux in the iron a certain exciting current is required, which is represented by I_{Ex} composed of the quantities I_W, which represents the power component, and I_M, which represents the magnetizing component. The secondary current is represented by

I_s, and the primary current I_P is then the vector sum of I_s and I_{Ex}. If a greater secondary load is introduced at M, the voltage E must be increased, which will also increase the value of I_{Ex}, thereby making a greater difference between the lengths of the lines I_s and I_P. Thus the ratio of a current transformer depends both upon

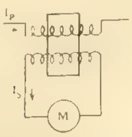

FIG. 1—CONNECTIONS OF CURRENT TRANSFORMER

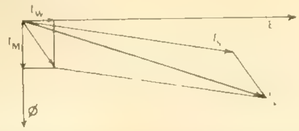

FIG. 2—VECTOR DIAGRAM OF CURRENTS

the value and power-factor of its secondary load. It should be noted, however, that the value of the exciting current is very small compared with the value of either the primary or secondary currents. In a good commercial current transformer the value of I_{Ex} is of the order of one percent of I_P.

If the secondary circuit becomes open circuited for any reason, the current I_s cannot flow and the currents I_P and I_{Ex} then become identical. In other words, the entire primary current flowing becomes magnetizing current and will saturate the iron. Since the product of the area of iron and number of turns for a current transformer is relatively small, this would not produce a seriously high voltage if the voltage wave form was a sine wave; in other words, the root-mean-square value of the secondary voltage will not be relatively high. The voltage wave produced, however, is not a sine wave but a wave having an enormously high peak value and it is this peak value which becomes dangerous.

The hysteresis loop of high grade transformer iron and also a sine wave of current is shown in Fig. 3, which is the current producing this hysteresis loop. When a current transformer is operating with open circuit secondary, since the primary is connected in series with a power line, the primary current both in value and wave form is determined principally by the character of the load on the system. It is assumed for

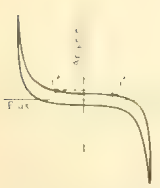

FIG. 3—HYSTERESIS LOOP AND CURRENT WAVE OF HIGH GRADE TRANSFORMER IRON

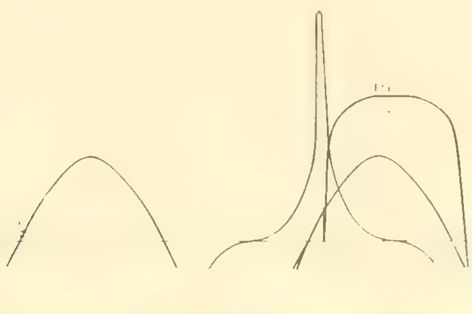

FIG. 4—RELATION OF CURRENT, FLUX AND VOLTAGE WAVES

the moment that this current wave form will be a sine wave. This being the case when the current has passed through zero and begins to rise in value, when some point a is reached, the flux density in the iron is that represented by a'. When the current rises to the value at b, the flux in the iron is changed to b'. It can readily be seen that the change in flux from a' to b' has taken place in a very short interval of time. Since voltage is proportional to the rate of change of flux, it is evident that this rapid change of flux will produce a very high voltage at that point. This is clearly illustrated in Fig. 4, in which I represents the sine wave current. The resulting flux wave will therefore be something like that represented by curve *Flux* and the voltage wave like that represented by E.

The open circuit voltage is not readily measured on account of its peculiar wave form and it is necessary to use some method by which the peak voltage can be obtained without drawing current from the current transformer. An oscillogram of the secondary voltage taken on a current transformer for street lighting service is shown in Fig. 5. The characteristic wave form is shown very clearly. However, the oscillograph takes an appreciable current, its maximum occuring at the point of the current wave where the instantaneous value of current is very low so that the oscillograph current may be a large percentage of the line current at that instant. This distorts the wave form of the magnetizing current and thereby reduces the peak voltage.

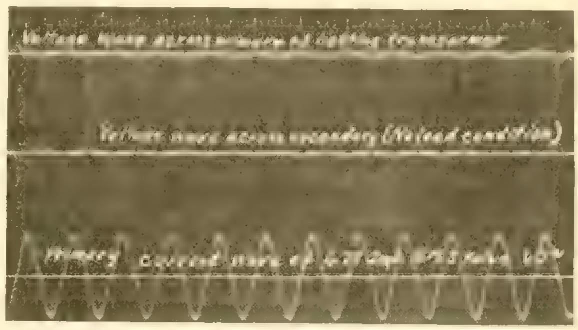

FIG. 5—OSCILLOGRAM OF THE SECONDARY VOLTAGE OF A CURRENT TRANSFORMER ON STREET LIGHTING SERVICE

Probably the best method for obtaining this peak voltage is the use of a form of crest voltmeter, originated by Dr. Clayton Sharpe. The scheme of connections of this instrument is shown in Fig. 6. The condenser C is charged through a hot cathode rectifier to the peak value of the alternating-current wave and the voltage of the charged condenser measured by means of an electrostatic voltmeter V. When this circuit is first closed, the current necessary to charge the condenser is drawn from the current transformer and as the condenser becomes charged this current falls off to very nearly zero in an exceedingly short time, so that for all practical purposes this voltmeter measures the peak voltage without drawing current from the circuit.

A modification of this scheme is shown in Fig. 7, which may be applied if an electrostatic voltmeter of the proper range is not available. In this scheme the alternating e. m. f. to be measured is opposed to a variable direct-current voltage through a hot cathode rectifier and a direct-current galvanometer in series. If the peak voltage of the alternating e. m. f. exceeds the direct-current voltage the galvanometer will show a deflection. In order to obtain the value of this voltage the

variable direct-current voltage is slowly raised until the galvanometer reading becomes zero. The reading of the direct-current voltmeter will then be equal to the peak voltage of the alternating e. m. f. Care must be taken not to raise the direct-current voltage above this value as the galvanometer will not indicate voltage in the reverse direction.

If the current wave in Fig. 3 be so distorted as to reduce its slope between the points *a* and *b*, the secondary peak voltage becomes reduced. This is exactly the effect of the primary peak voltage of the current transformer operating with open circuited secondary. Under normal conditions the primary voltage drop is

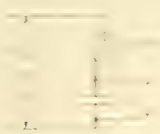

FIG. 6—SCHEME OF CONNECTIONS OF CREST VOLTMETER
To obtain voltage peak.

FIG. 7—ANOTHER SCHEME OF CONNECTIONS
When voltmeter of proper range is not available.

negligible, but when operating on open circuit this high peak voltage may be an appreciable percentage of the total line voltage. Its effect on the wave shape of current will also depend to some extent upon the power-factor of the load on the line. If a current transformer of 1:1 ratio is connected on a low voltage circuit the peak voltage of the current transformer will cause a decided change in the primary current wave form, so that a balance is maintained between distorted primary current and distorted voltage. If the transformer ratio be increased, that is the number of primary turns reduced, keeping the secondary turns constant, the value of the primary voltage is thereby reduced and its effect on the current wave form is lessened. If, again, the voltage of the circuit be raised the primary voltage of the current transformer becomes a less percentage of the line voltage and the effect on the primary wave form is still further lessened. It then seems logical to conclude that the peak voltage of the current transformer is a function of the k. v. a. of the circuit into which it is connected; that is a 5 to 5 ampere current transformer on a 440 volt line should give the same open circuit voltage as a 10 to 5 ampere current transformer on a 220 volt line or a 20 to 5 ampere current transformer on a 110 volt line. This conclusion has been verified by experimental data and a curve showing the variation of peak voltage with k. v. a. of the circuit is shown in Fig. 8. This curve is plotted from data obtained from current transformers of various ratios tested on circuits of varying voltage. All the current transformers had the same magnetic circuit and same secondary turns, the only variable being the primary currents. They were tested on a 60 cycle circuit having a relatively high power-factor load. The constants of the particular type of transformers tested are as follows: Secondary turns 238; area of iron 2 ¼ square inches; mean length of magnetic circuit 16 inches.

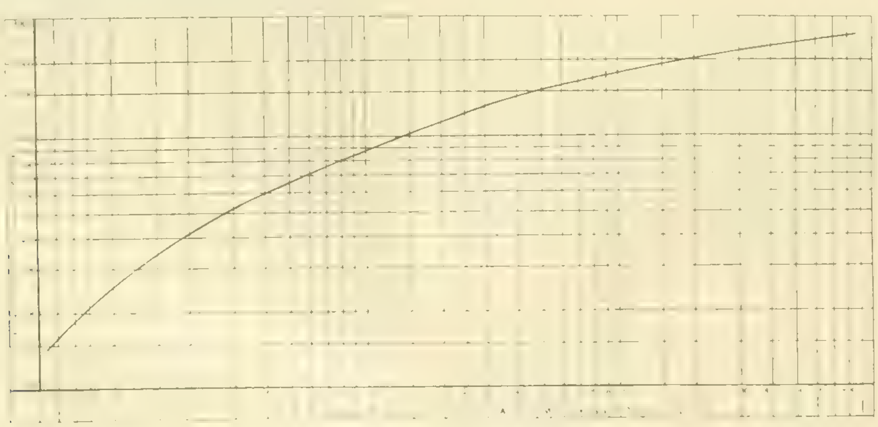

FIG. 8—VARIATION OF PEAK VOLTAGE OF A CURRENT TRANSFORMER WITH THE K.V.A. OF THE CIRCUIT

No general expression can be given for applying the open circuit voltage curve to other transformers, or other frequencies as there are many factors which affect this value. In general however, the voltage will be increased with greater area of magnetic circuit, greater number of secondary turns or higher frequency, while the converse is also true, in that the voltage will be diminished with a smaller number of secondary turns or lower frequency.

It is evident that the voltage of a current transformer operating with secondary open circuited may become very dangerous. While the amount of power the transformer can deliver is limited, and although any current drawn through a high resistance shunted across the secondary terminals tends to decrease the peak voltage, there is certainly sufficient energy involved to make personal contact highly dangerous, and most certainly fatal if the ampere-turns of the transformer are relatively high (1000 or more) and the circuit is carrying 100 k. v. a. or more.

The Essentials of Transformer Practice—VII

Heating

E. G. Reed

In transformer operation, the amount of temperature rise is important because of the necessity of keeping the temperature of the windings from exceeding a safe value. While the temperature of the magnetic circuit is not important, since the use of silicon steel renders it non-aging even at relatively high temperatures, yet its temperature must be limited because of its proximity of the windings.

A temperature rise curve for a transformer winding may be divided into three parts, as shown in Fig. 1. From the origin, the first part of the curve is practically a straight line, which means that when a cold transformer is put into service, the rate of temperature rise is nearly constant for a time. This condition signifies that the greater part of the heat from the losses is absorbed in raising the temperature of the transformer, and that very little heat is radiated into the air. The rate of temperature rise is represented by the slope of

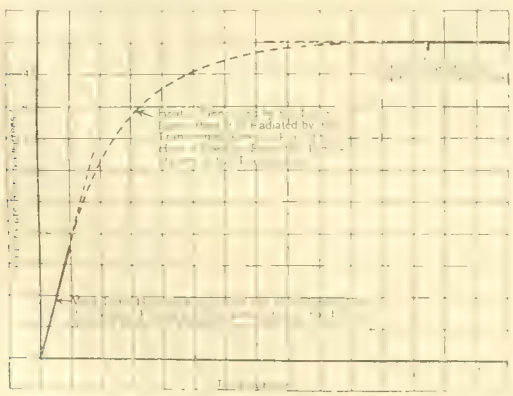

FIG. 1 TEMPERATURE RISE OF A TRANSFORMER WINDING
Showing the three parts into which the curve may be divided.

the line, and depends only on the amount and kind of material in the transformer and on the total amount of heat generated by the losses.

The second part of the curve represents the condition when the initial rate of temperature rise is not maintained, because of the heat beginning to flow away from its source of generation. After the heat commences to be radiated from the surface of the transformer case into the surrounding air, the rate of rise of temperature falls very rapidly. The temperature rise of the transformer continues to increase at a decreasing rate, until the heat is radiated at the same rate as it is being generated by the losses. When this condition, represented by the third part of the curve in Fig. 1, is reached, the temperature rise curve has flattened out showing that the rate of increase of temperature is practically zero, and the maximum temperature rise has been obtained.

INITIAL RATE OF TEMPERATURE RISE

When putting a cold transformer into service, the initial rate of temperature rise of the windings depends only on the copper loss, the amount of copper in the coils and the specific heat of the copper. This condition exists only for a short time until the heat from the windings begins to be imparted to the oil and the other parts of the transformer. The specific heat of copper is 0.092, or 0.092 gram-calories of heat are required to raise the temperature of one gram of copper one degree C. Putting this value of the specific heat in more convenient terms, it is found that approximately 2.9 watt-minutes are required to raise the temperaure of one pound of copper one degree C.

In calculating the initial rate and the actual temperature rise after a given time, before the rise is arrested by conduction, convection or radiation of heat, this relation may be expressed in the following form:—

$$\frac{t}{T} = \frac{W_c}{2.9} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

Where t is the rise in temperature expressed in degrees centigrade in T minutes, or $\frac{t}{T}$ is the initial rate of temperature rise and W_c is the watts copper loss per pound of copper in the winding.

Example:—What is the initial rate of temperature rise in a transformer winding when the copper is operating at seven watts per pound? From equation 1,—

$$\frac{t}{T} = \frac{7}{2.9} = 2.4[illegible] \text{ degrees C. per minute.}$$

Example:—At what value of watts per pound of copper is it permissible to work a transformer which is used for starting a motor when the time required for starting is one minute, and the permissible temperature rise is 100 degrees C.? From equation 1,—

$$W_c = \frac{[illegible]}{[illegible]} \ldots = [illegible] \text{ watts per pound.}$$

FINAL TEMPERATURE RISE OF THE OIL

The first step in predetermining the temperature rise of the windings of a transformer, after the straight line part of the temperature rise curve has been passed, is to determine the temperature rise of the oil. The rate P at which a hot body emits heat is very nearly proportional to the excess t of its temperature above that of its surroundings, and roughly proportional to the area a of its surface, that is, $P = a\,e\,t$ in which e is the proportionality factor, which is called the emissivity of the surface of the body. Solving this equation for t gives,—

$$t = \frac{P}{e\,a} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

The value of e for various types of transformer

cases when P is expressed in watts, a in square inches and t in degrees C. is as follows*:—

For smooth cast iron cases.................... $e = 0.0075$
For smooth boiler iron cases................... $e = 0.007$
For corrugated cast iron cases.................. $e = 0.0059$
For corrugated sheet iron cases................. $e = 0.0043$
(4 3/32 inch pitch and 3½ inch depth of corrugation)

These constants are based on approximately 40 degrees C. rise of the oil and the radiating surface calculated from the hot oil level in the case at approximately 80 degrees C.

Example:—What will be the temperature rise of the oil in a 50 k.v.a. transformer, which has a total loss of 850 watts and a corrugated cast iron surface of 3600 square inches? From equation 2,—

$$t = \frac{[illegible]}{0.00[illegible] \times 3600} = [illegible] \text{ degrees C.}$$

TEMPERATURE GRADIENT BETWEEN WINDINGS AND OIL

The difference between the temperature rise of the transformer winding as determined by the increase of resistance method and the temperature rise of the oil, is the temperature gradient between the windings and the oil. The temperature gradient, as thus determined, is less than the maximum gradient which might be determined by a thermocouple placed in the hottest spot in the windings. It is generally assumed that the temperature of the hottest spot is never greater than about 10 degrees C. above the average temperature indicated by the increase of resistance measurement. The measured temperature gradient as indicated by the increase of resistance method is usually between five and fifteen degrees C. The value of this gradient in a particular transformer depends upon the area of the winding exposed to the oil and the thickness of the coils. The nature of the coil insulation will also affect the value of the gradient, as a high-voltage winding having a relatively large amount of insulation, will be likely to have a high gradient, other things being equal. The viscosity of the cooling oil will also have a slight effect on the gradient.

In a particular transformer it is evident that the gradient will be proportional to the total loss in the winding, and will therefore vary as the square of the load on the transformer. For example, a transformer which has a ten degrees C. gradient at 100 percent load will have approximately 15.5 degrees C. gradient at 125 percent load.

It is possible to predetermine the temperature gradient in a coil approximately by assuming that the total drop in temperature is that used to force the heat through the insulation and copper in the coil. The rate of flow of heat through a conducting body may be expressed by the relation,

$$P = \lambda \frac{t}{i} a \qquad (3)$$

Where λ represents the heat conductivity of the material, a the area of the section through which the heat is flowing expressed in square inches, i the thickness of the material and t the resulting temperature drop or temperature gradient. Equation (3) may be put into the form

$$t = \frac{1}{\lambda} \frac{i}{a} P = \frac{1}{\lambda} W_a i \qquad (4)$$

Where W_a is the watts per square inch being forced through the section of area a. The approximate value of λ for fibrous insulating material expressed as the number of gram calories of heat per second being forced through a cubic centimeter of the material with a drop of temperature of one degree centigrade, is 0.00032. Expressing this value in the more convenient form of watts being forced through a cubic inch, with a drop of temperature of one degree centrigrade, for fibrous insulation $\lambda = 0.0053$ approximately.

Example:—What is the temperature gradient through a sheet of insulating material 1/16 inch thick, through which heat is being forced at the rate of one watt per square inch. From equation (4)

$$t = \frac{1}{0.0053} \times 1.0 \times 0.062 = 11.6 \text{ degrees C.}$$

This indicates that a solid sheet of insulation close up against a coil cuts off the flow of heat across the area covered to a considerable extent. To get the total gradient in the coil in this case, the drop in temperature within the coil would have to be added to that through the external insulating sheet. Each coil in a trans-

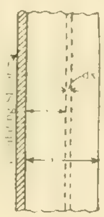

FIG. 2—SECTION OF A TRANSFORMER COIL
Adjacent to a sheet of insulating material.

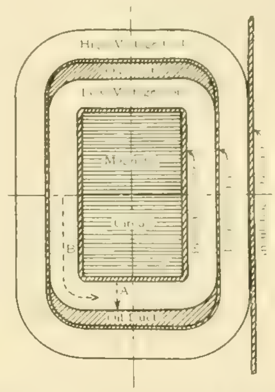

FIG. 3 SECTION OF ONE LEG OF A CORE-TYPE TRANSFORMER
With concentric coils.

former winding should have, if possible, some surface exposed to the cooling oil, unless some other condition exists which permits the heat to escape. Coils wound with relatively heavy conductors will have a considerable amount of heat conducted out through their leads. A section through a coil which is adjacent to an insulating sheet is shown in Fig. 2. The heat is generated uniformly throughout the coil, and since one side is insulated the greater part of the heat must pass out through the free surface. This condition is therefore different from that given in the example above, where the heat is forced through the insulating sheet by an outside source and the sheet has no loss generated within itself. The drop in temperature across the small section of the coil of length dx in Fig. 2, by equation 4 is,—

$$dt = \frac{1}{\lambda} W_a dx$$

The total loss in the part of the coil between the insulating sheet and the small section dx, is $\frac{x}{i} W_a$. In this case W_a is the watts per square inch of the coil surface exposed to the cooling action of the oil. Then,—

*See *Proc. A. I. E. E.* Vol. XXX No. 3, page 463.

$$dt = \frac{1}{\lambda}\frac{W_a}{i}xdx$$

or

$$t_{max.} = \frac{1}{\lambda}\frac{W_a}{i}\int_0^i xdx = \frac{1}{\lambda}\frac{W_a}{2}i \quad \ldots\ldots\ldots\ldots\ldots (5)$$

This is the gradient from a point adjacent to the insulating sheet across the entire coil, and is therefore greater than the difference between the point of average temperature and the temperature of the oil. Assuming that the average temperature along this path of heat flow is at a distance of 0.5 i from the insulating sheet

$$t_{av.} = \frac{1}{\lambda}\frac{W_a}{i}\int xdx = \frac{1}{\lambda}\frac{W_a}{2.7}i \quad \ldots\ldots\ldots\ldots\ldots (6)$$

A comparison of these two equations indicates that the average gradient, or the value which would be given by an increase of resistance measurement will be something like 75 percent of the maximum gradient. Equations *5* and *6* assume that the insulating material is distributed uniformly throughout the coil, and i is the total thickness of this insulation, or is the total thickness of the coil exclusive of the copper. Ordinarily the temperature drop through the copper may be ignored because of the shortness of the heat path through the copper, and because of the relatively great heat conductivity of copper. The heat conductivity of copper is 8.5 as compared to 0.0053 for fibrous insulating material, so that the temperature drops through paths of heat flow of the same dimensions would be in the ratio of 1 to 2500 for the two materials. If both sides of the coil are exposed to the cooling oil, the heat can be conducted in both directions, and the value of i in equation (5) and (6) should be taken as one-half of the total thickness of insulation in the coil.

Example:—What is the average temperature drop along the path of heat flow shown by the dotted line in Fig. 3, when the value of W_a is 0.8 and the total thickness of the insulation along this path is 0.2 inches? From equation (6)

$$t_{av.} = \frac{1}{0.0053} \times \frac{1.0}{2.7} \times 0.2 = 14 \text{ degrees C.}$$

It must not be taken for granted that this method of calculating temperature gradients, with the constants given, will always give accurate results. The value of λ varies for the different insulating materials, and the effect of the impregnation treatment on the different methods of insulation is another variable. The general conditions vary with different coil arrangements, and with different types of transformers. In the simplest case there are a number of heat flow paths in series, in parallel or in series-parallel, of which only the most important ones can be considered in a particular calculation. While ordinarily the drop in temperature along the copper is negligible, there are certain cases similar to that along the dotted line *B* in Fig. 3, where the gradient is appreciable under certain conditions. This gradient can be calculated with some degree of certainty because the heat conductivity of copper is a fixed quantity. For this case it is more convenient to have equation *6* in terms of the watts per pound of copper loss in the coil W_c, than in terms of W_a. Since $W_a = 0.321\ W_c i$, equation *6*, may be written, substituting the value of 8.5 for the heat conductivity of copper,—

$$t_{av.} = 0.014\ W_c i^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Example:—What is the temperature gradient along the length of the conductors corresponding to the dotted line *B* in Fig. 3, in a transformer coil, when the length of the path is approximately five inches, and the copper is working at five watts per pound? From equation (7)

$$t_{av.} = 0.014 \times 5 \times 5^2 = 1.75 \text{ degrees C.}$$

HEATING CURVE

Assume that the transformer is composed of a mass of material weighing *G* pounds which has a specific heat of *S*, expressed as the number of watts required to raise the temperature of one pound of the material one degree C. per minute. At some point on the heating curve the small increase dt in the temperature rise, occurs during a small interval of time dT. The rate of increase of temperature rise is,

$$\frac{dt}{dT} = \frac{L-P}{GS}$$

Where L is the total watts loss in the transformer and P the watts being radiated into the air with the transformer at temperature t. The watts L-P is the rate at which heat is being absorbed in raising the temperature of the transformer, and this divided by GS

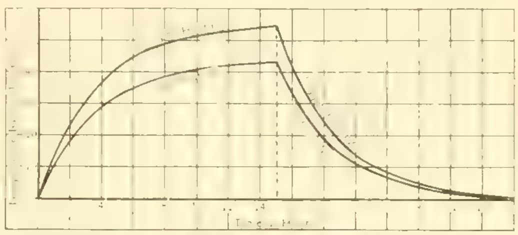

FIG. 4—RELATION OF HEATING AND COOLING FOR THE OIL AND COPPER IN A TRANSFORMER

Obtained by the use of equations (9) and (11).

or the watt minutes required to raise the temperature of the transformer one degree, gives the rate of temperature rise increase at this point on the heating curve. Substituting the value of P from equation *2* gives,—

$$\frac{dt}{dT} = \frac{L - act}{GS}$$

When the final temperature rise has been reached or the heating curve has flattened out,—

$$L = P = a\,e\,t_r$$

Where t_r is the final temperature rise of the transformer, then,—

$$\frac{dt}{dT} = \frac{ea\,(t_r - t)}{GS}$$

or

$$-\frac{dt}{t_r - t} = -\frac{ea}{GS}dT$$

The integral of this expression is,—

$$\log_\epsilon (t_r - t) + Constant = -\frac{ea}{GS}T$$

Since, when T is equal to zero t is also equal to zero,—

$$Constant = -\log_\epsilon t_r$$

Therefore,—

$$\log_\epsilon (t_r - t) - \log_\epsilon t_r = -\frac{ea}{GS}T$$

$$\frac{t_r - t}{t_r} = \epsilon^{-\frac{ea}{GS}T}$$

or

$$t = t_r\left(1 - \epsilon^{-\frac{ea}{GS}T}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

This expression may be put into the form,—

$$t = t_r\left(1 - \epsilon^{-\frac{T}{T_o}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where,—

$$T_o = \frac{GS}{ea} \text{ or } \frac{GSt_r}{eat_r} = \text{[illegible]} \quad \ldots (10)$$

Where T_o = the time required to reach final temperature if there is no heat radiation to the surrounding air. When T is equal to T_o, that is when $\frac{T}{T_o}$ is equal to unity, equation (9) indicates that the temperature rise would be approximately 63 percent of the final rise, or in other words in time T_o the transformer would reach 63 percent of the temperature it would attain if there was no radiation of heat.

Equation *9* will apply either to the temperature rise of the oil or of the windings. When the rise of the oil is being considered, t_r refers to the final rise of the oil, and for the windings t_r represents the final rise of the oil plus the final value of the temperature gradient between the oil and windings.

No allowance is made for the increase in the copper loss of the transformer as its temperature rises. If the value of the copper loss used in calculating the data for a heating curve is approximately the loss at the temperature at which the heating curve becomes flat, each point on the curve will be slightly higher than the actual temperature of the transformer. This error is just opposite to another introduced by the changing viscosity of the oil as the transformer heats.

The values for the specific heat of copper, iron and oil, expressed in watt minutes per pound per degree centigrade are approximately as follows,—

S_c = 2.0 for copper
S_1 = 3.6 for iron
S_o = 1.5 for oil.

Example:—What is the time constant T_o for a transformer when G_c = 45 lbs., G_1 = 188 lbs., G_o = 34 lbs., e = 0.0059 and a = 700 square inches.

$G_c S_c + G_1 S_1 + G_o S_o = 45 \times 2.0 + 188 \times 3.6 + 34 \times 1.5$ = 862.

From equation *10*,—

$$T = \frac{862}{0.0059 \times 700} = \text{[illegible] minutes} = \text{[illegible] hours}$$

Example:—Draw the curves for the temperature rise of the oil and the windings of the transformer whose constants are given in the preceding example, whose final temperature gradient is 12 degrees centigrade, and the sum of whose losses at 75° C. is 180 watts?

From equation 9,—

$$t_r \text{ for the oil} = \frac{180}{0.0059 \times 700} = 43 \textit{ degrees C.}$$

t_r for the windings = *43* + *12* = *55 degrees C.*

Then for the oil, from equation (9)

$$t = 43\left(1 - \epsilon^{-\frac{T}{\text{[illegible]}}}\right)$$

which is a relation between time T and temperature rise t, for this particular transformer. The curve is shown in Fig. 4, for both the oil and the windings.

For convenience in plotting similar curves, values of $\left(1 - \epsilon^{-\frac{T}{T_o}}\right)$ for various values of $\frac{T}{T_o}$ are given in the form of a curve in Fig. 5, which indicates that on a heating curve a transformer will reach 98 percent of its final temperature, or practically a constant temperature for a value of $\frac{T}{T_o}$ of 4.0. If the time constant of a particular transformer is three hours or less, its final temperature will be reached in not more than 12 hours. If its time constant is more than three hours, it will require more than 12 hours to reach a practically steady temperature.

COOLING CURVE

The cooling curve of a transformer is sometimes important in determining its suitability to take care of special service conditions. The equation for the cooling curve may be determined by the same method as used for the heating curve.

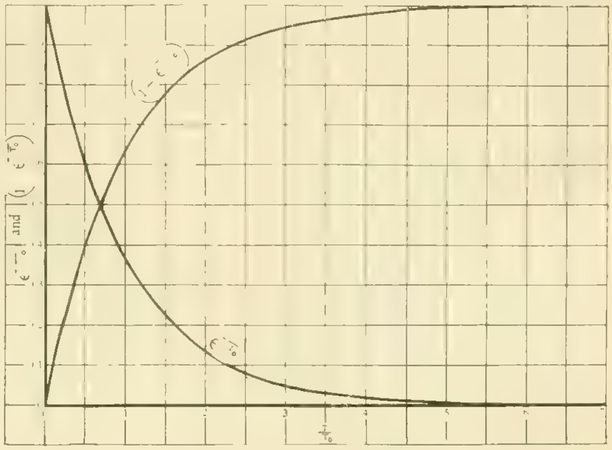

FIG. 5 RELATION OF $\left(1 - \epsilon^{-\frac{T}{T_o}}\right)$ AND $\epsilon^{-\frac{T_o}{T}}$

For use in estimating the temperature rise of transformers under various service conditions.

The amount of heat radiated by the transformer during a small interval of time dT is,—

$$dPdt = a\,e\,t\,d\,T$$

From equation *2*, let dt be the small reduction in temperature of the transformer during this period of time dT. The amount of heat which must be taken from the transformer to reduce its temperature dt degrees C., is $GSdt$. Therefore,—

$$aetdT = GSdt$$

or

$$-\frac{dt}{t} = -\frac{ea}{GS}dT$$

The integral of this expression is,—

$$\log_\epsilon t + Constant = -\frac{ea}{GS}T$$

When T is equal to zero, t is equal to t_r, therefore—

$$Constant = -\log t_r$$

or

$$\frac{t}{t_r} = \epsilon^{-\frac{ea}{GS}T}$$

or

$$t = t_r\,\epsilon^{-\frac{ea}{GS}T}$$

or

$$t = t_r \epsilon^{-\frac{T}{T_0}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

Where T_0 has the same value as given by equation *10*. To assist in numerical applications of this equation Fig. 5 gives the value of $\epsilon^{-\frac{T}{T_0}}$ for various values of $\frac{T}{T_0}$.

Example:—Draw the cooling curves for both the oil and the windings, for the same transformer as that covered by the preceding examples?

From equation *11*, for the oil,—

$$t = 43\,\epsilon^{-\frac{T}{\text{[illegible]}}}$$

which is the relation between time T and the temperature rise t of the oil, as the transformer cools, starting with the oil at 43 degrees C. The cooling curve is shown in Fig. 4.

OVERLOAD TEMPERATURE RISE CURVES

Having plotted, with the use of equation *9* or from tests, the curves showing the increase of the temperature rise of the oil and windings with time, starting with 100 percent load, the corresponding curves for any other load may readily be determined. The calculation of overload temperature curves from the 100 percent load values is based on the fact that the temperature rise of the oil is proportional to the total loss in the transformer and temperature rise of the windings above the oil is proportional to the copper loss. Suppose it is desired to draw the temperature rise curves for 125 percent load. Assume that after eight hours operation at 100 percent load the oil rise is 34 degrees C. and the rise of the windings is 45 degrees. If the normal iron loss of the transformer be 33 percent and the normal copper loss be 67 percent of the total loss, a load of 125 percent will produce a copper loss of 104 percent, the copper loss increasing as the square of the load. The total loss for this load will then be 137 percent, therefore the temperature rise of the oil will be $1.37 \times 34 = 46$ *degrees C.* The rise of the copper above the oil will be $(1.25)^2 \times 11 = 17$ *degrees C.* The temperature rise of the copper will then be $46 + 17 = 63$ *degrees C.* This procedure can be repeated for a sufficient number of points to enable the construction of the complete temperature curve. The temperature rise curve of the windings for no-load, that is, the temperature rise in oil due to the core loss only, can be determined by the same method. If the normal core loss is 33 percent of the total loss, the temperature rise of the oil and the winding also will, in this case, be $0.33 \times 34 = 11$ *degees C.*

The curves given in Fig. 6, which show the rise of the oil at no-load and at 100 percent load and the copper at 100, 125 and 150 percent loads, have been determined by test, and they check up very closely with the theoretical curves as outlined above. The temperature rise of the oil is determined by a thermometer and of the windings by the increase of resistance method. These curves do not represent any particular size of transformer, but rather that characteristics of a line of distributing transformers of from one to 50 k.v.a.

Example:—As an example of the first case, suppose it is required to find the temperature rise of a transformer that is operating with no-load and then receiving a 100 percent load for four hours, followed by a 150 percent load for two hours. From the temperature curves in Fig. 1, it is seen that the windings have approximately a 12 degree rise, due to the iron loss only. To obtain the temperature rise of the windings after four hours at 100 percent load, follow the 100 percent load temperature rise curve forward for a period of four hours from the point where it reached a temperature rise of 12 degrees C. This gives a temperature rise of approximately 38 degrees. When the 150 percent load is placed on the transformer it has a temperature rise of 38 degrees C., and will then continue to rise in temperature as indicated by the 150 percent load curve. Starting from the 38 degree C. rise, on the 150 percent load temperature rise curve, a transformer at the end of a two-hour period will have reached an approximate temperature of 63 degrees C. In this case its original temperature rise, due to its core loss, had little effect on its final temperature. Although it had a temperature rise of 12 degrees C. when the 100 percent load was started, this increased its temperature rise only two degrees C. at the end of the four-hour run at 100 percent.

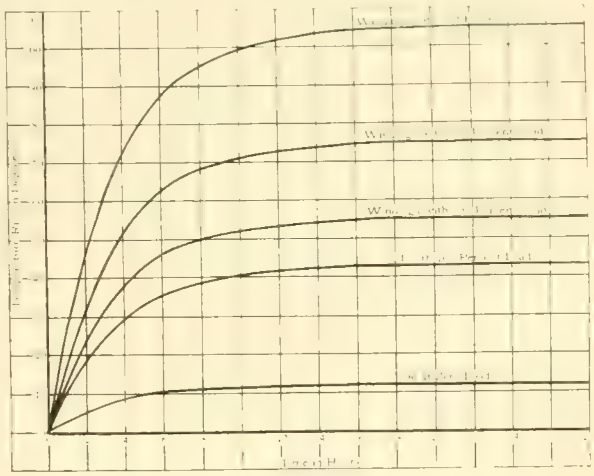

FIG. 6—TYPICAL TEMPERATURE CURVES
With different loads on the transformers.

SAFE MAXIMUM OPERATING TEMPERATURES

In determining the permissible load at which commercial transformers can be operated for a given time, and the permissible time for a given load, a maximum safe operating temperature should not be exceeded. It is generally understood that a safe maximum temperature for continuous operation is about 105 degrees C. Making an allowance of 10 degrees C. for hot spots and 40 degrees for the air temperature, gives a maximum temperature rise of 55 degrees C. This temperature rise may be exceeded for short periods of operation.

Emergency Power for Suburban Street Car Lines

A. E. Boggs

MAINTENANCE of voltage on a stub end of a street car line is one of the annoying problems of street railway transportation. This is especially the case when the traffic is heavy at the extreme end of the line, as for example when a large factory is located in the suburbs. In this case the problem is especially complicated by the fact that the heavy morning and evening peaks, caused by carrying workmen to and from the factory, are of short duration so that the heavy feeders required to maintain voltage during the peaks would be practically idle during most of the day.

In such cases, where the manufacturing plant has a power station of sufficient capacity, this problem can often be solved to the mutual advantage of all parties interested by arranging either for the interchange of power by the railway company and the factory power station or the purchase of power. This power will be taken by the railway at times when the load on the factory power plant will normally be low, i. e. before work commences in the morning, and after the factory is shut down in the evening, so that it can be provided even by a plant which is fully loaded during the day. This plan is especially advantageous where the railway power plant is already overloaded, which is the case in many localities at the present time, especially if the same plant carries both the industrial and railway load in a given community. Furthermore this load will be removed from the railway power station at the time of their heaviest power demand, a consideration which at the present time of congested service and large power requirements, may be of considerable importance. In such a case, the generating capacity of the factory power plant is added to that of the railway plant.

FIG. 1 SKETCH SHOWING LOCATION OF THE WESTINGHOUSE PLANT AT EAST PITTSBURGH, PA.

The main power plant of the Pittsburgh Railways Company is located at Brunots Island about 12 miles away in an air line. From the Westinghouse plant, one car line runs up the valley on Air Brake Avenue to Wilmerding, etc. Another runs up a long, steady grade on Ardmore Boulevard to Wilkinsburg and Pittsburgh; a third line runs to Swissvale and Wilkinsburg over heavy grades, and a fourth to Second Avenue, Pittsburgh via Braddock and Homestead.

A typical example of the working out of such an instance in the Pittsburgh district is illustrated by the map, Fig. 1. Due to the tremendous increase in the number of men employed at the Westinghouse plants at East Pittsburgh and Wilmerding, the existing overhead equipment of the Pittsburgh Railways Company in this vicinity was severely taxed for approximately two hours in the morning and for a similar period in the evening, at a time when the railway company's generating capacity was also heavily loaded. In view of the attendant circumstances, it was considered better to use power from an existing plant, ideally located for the purpose, than to install an additional substation or even increase the railway feeder capacity. From the factory standpoint, the additional load simply broadened the load curve without adding materially to its height, as shown in Fig. 2. Just at the time when the peak load is on the Railways Company lines, the Electric Company's load is relatively light, and by means of a large rotary converter the Electric Company supplies power to the Railways Company's feeders at 500, 550, 600, or 650 volts, according to line conditions and the power needs of the Pittsburgh Railways Company.

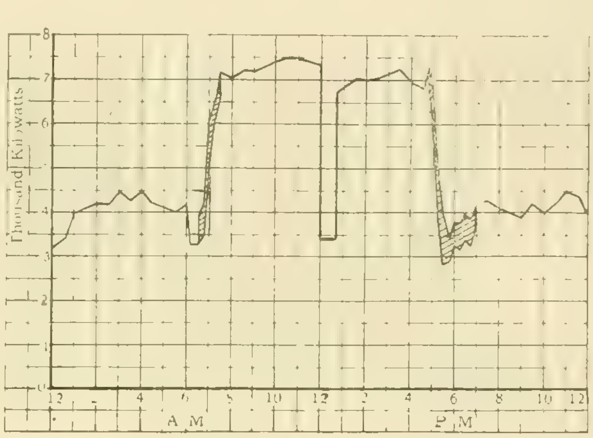

FIG. 2—TYPICAL LOAD CURVE OF THE WESTINGHOUSE ELECTRIC WORKS AT EAST PITTSBURGH

The shaded portions show the power lift given to the Pittsburgh Railways Company in the morning and evening rush periods.

This arrangement has been working for approximately a year with very satisfactory results. With both companies the main consideration in making such an arrangement was the improved facilities for getting the employees to and from their work promptly, the increased facilities and minimized delays being of more importance than the rates for the interchange or purchase of power.

The Engineering Evolution of Power Plant Apparatus—XXV

A Historical Review of Steam Turbine Progress

Francis Hodgkinson

THE PAST two decades have seen a growth in the size and economy of steam turbines beyond the most optimistic expectation of twenty years ago, as was shown graphically last month in Figs. 4, 5 and 6. The types of machines which represent the various stages in this development are illustrated and their performances are given in the following discussion.

1899

The 400 kw 3600 r.p.m. turbines, driving revolving armature, 440 volt generators shown in Fig. 11 were installed at the plant of the Westinghouse Air Brake Company. These turbines are still in service. Sixty-six machines of this size were sold.

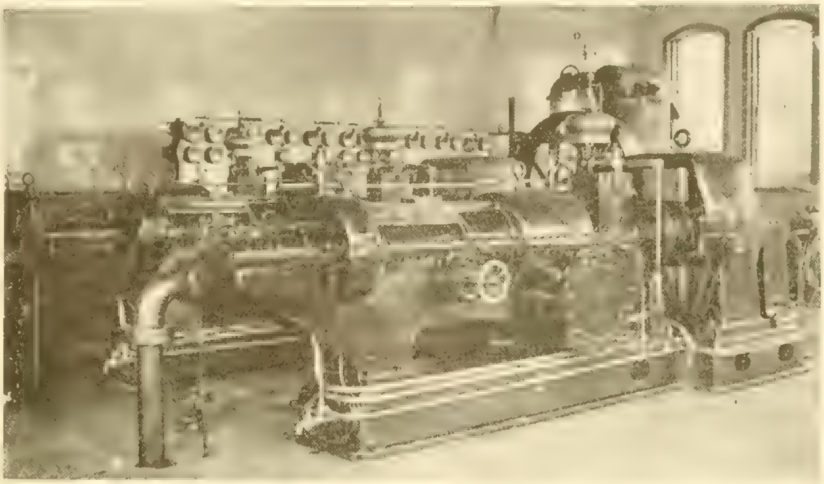

FIG. 11—400 KW, 3600 R. P. M. STEAM TURBINE DRIVING REVOLVING ARMATURE, BIPOLAR, 440 VOLT GENERATOR

PERFORMANCE

Kw Load	Steam Press Lbs. Gage	Superheat Degrees F.	Vacuum In. Hg.	Lbs. per Kw Hr.	Eff. Ratio
300	125	0	27	22.0	54.1

1900

The 2000 kw turbine for the Hartford Electric Light Company shown in Fig. 12 was shipped in 1900. This turbine was of the straight Parsons single-cylinder construction, and was designed to operate at 1200 r.p.m.

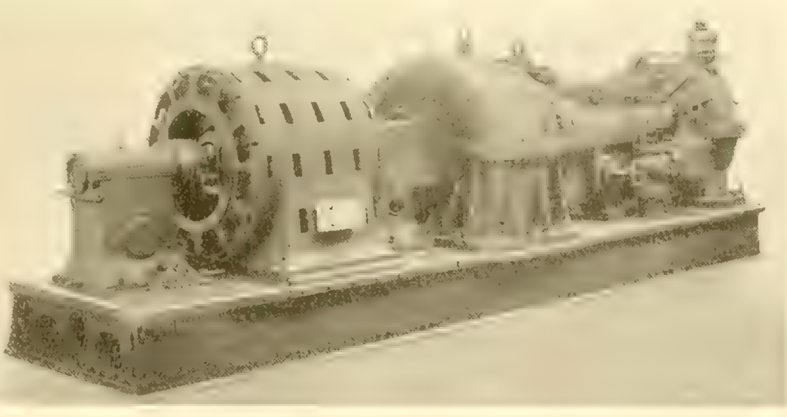

FIG. 12—2000 KW, 1200 R. P. M. STRAIGHT PARSONS SINGLE-CYLINDER STEAM TURBINE

PERFORMANCE

Kw Load	Steam Press. Lbs. Gage	Superheat Degrees F.	Vacuum In. Hg.	Lbs. per Kw Hr.	Eff. Ratio
1998	155	41.6	26.9	19.1	58.2

1903

The 1000 and 1500 kw two-cylinder machines arranged in tandem, shown in Fig. 13, are of the straight Parsons design. Sixteen of these turbines were built.

1904

The single-cylinder machines of 1000 kw rating were built of straight Parsons design, the turbine as shown in Fig. 14 being operated either at 1500 or 1800 r.p.m. One hundred and twenty-nine of these turbines were sold in this year.

1905

Some large machines sensible of being given a normal rating of either 5500 or 7500 kw were shipped in 1905. These were regarded at the time as of unprecedented capacity. They operated at 750 r.p.m. and were also of straight Parsons design, as shown in Fig. 15. Fourteen of these machines were built. Twelve of these are still in serviceable operation.

1905 to 1909

Between these years a very large number of straight reaction turbines were built of similar type to those described under 1903, varying in capacity from normal ratings of 300 kw to normal ratings of 3000 kw, speeds varying from 3600 to 1200 r.p.m., and others at 7500 kw capacity at 750 r.p.m.

1909

Improvement in generator construction permitted increased capacities at a given speed, as it was then considered undesirable to materially increase the blade speeds. A feature was developed for providing the turbine with low-pressure elements of double-flow construction, thus doubling the capacity of those elements and replacing the first barrel of Parsons blading in the older design machines, whose dimensions were small and consequently subject to large leakage losses, by an impulse element, producing what is now known as a single-double flow turbine.

During this year there were shipped a number of 6000 kw, 1500 r.p.m. normal rated machines as shown

in Fig. 16. At the same time some 10000 kw, 750 r.p.m. machines of the same construction were built and are shown in Fig. 17. Also during this year there was shipped a 1500 r.p.m., 10000 kw maximum rated machine to the Metropolitan Street Railway Company of Kansas City, of single-double-flow construction. With a load of 8551 kilowatts at 166.5 pounds, gage steam pressure at 75.4 degrees F. superheat and a vacuum of 28.73 inches mercury, the steam consumption of this turbine was 14.50 pounds per kilowatt-hour, and its efficiency ratio was 65.0.

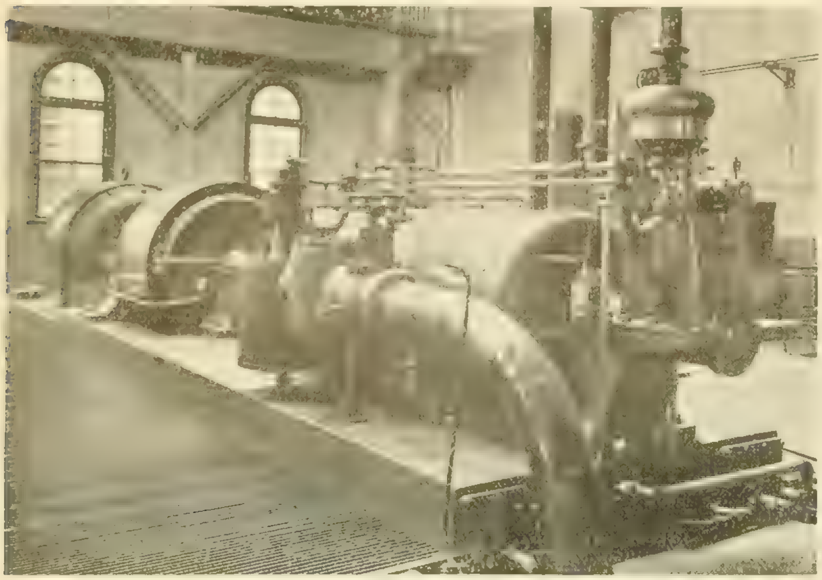

FIG. 13—1500 KW, TWO-CYLINDER, STRAIGHT- PARSONS TYPE STEAM TURBINE, WITH CYLINDERS ARRANGED IN TANDEM

PERFORMANCE

Kw Load	Steam Press. Lbs. Gage	Superheat Degrees F.	Vacuum In. Hg.	Lbs. per Kw-Hr.	Eff. Ratio
1475	150	50	27.01	18.5	59.8

In the same year an epoch-making machine was shipped to the City Electric Company of San Francisco of 10000 kw normal rated capacity, 15000 kw maximum, at 1800 r.p.m. This machine, as shown in Fig. 18, was of double-flow construction, except that the impulse element only was single flow, all of the reaction blading being double-flow.

1910

A 2000 kw normal rated, 3000 kw maximum machine was developed of precisely similar design to the 10000 kw turbine, except that it was arranged to operate at 3600 r.p.m. In the absence of authentic tests its performance at 2000 kw is stated to be 15.4 lbs. per kw-hr., giving an efficiency ratio of 63.5, with 175 lbs. gage steam pressure, 100 degrees F. superheat and 28.0 inches mercury vacuum.

1911

Some bleeder turbines as shown in Fig. 21 were developed of 750 to 1500 kw capacity for industrial plants where heating was required for some industrial process, also for small communities which required exhaust steam in the winter time for district heating, the turbine operating completely condensing in the summer. These turbines automatically maintain the desired pressure in the heating system, and that which is not required for heating purposes passes through the low-pressure turbine elements to the condenser.

1912

A 3500 kw normal rated, 4500 kw maximum, double-flow turbine as shown in Fig. 20 was shipped in this year, the impulse element only being single-flow, designed to operate at 3600 r.p.m., in which blade speeds as high as 500 feet per second were employed. In the absence of authentic tests their performance is stated to be that shown in connection with Fig. 20. In this year two of the largest geared direct-current units of 3750 kw capacity were shipped. These turbines, which were shown in Fig. 1*, operate non-condensing against 20 pounds back pressure, the gear reduction being from 1800 to 180 r.p.m. The operation of these gears and turbines has been of a most satisfactory character.

1913

A 20000 kw maximum rated turbine operating at 1500 r.p.m., as shown in Fig. 23, and a 15000 kw maximum turbine operating at 1800 r.p.m. were developed

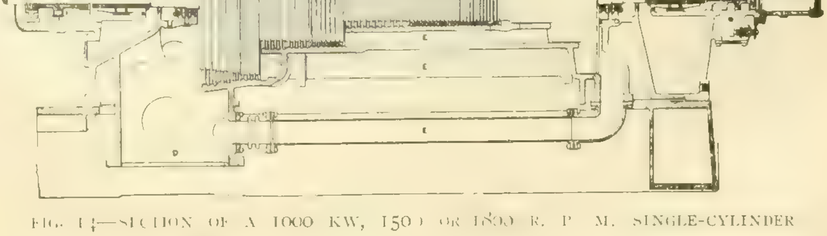

FIG. 14—SECTION OF A 1000 KW, 1500 OR 1800 R. P. M. SINGLE-CYLINDER STEAM TURBINE OF THE STRAIGHT PARSONS TYPE

PERFORMANCE

Kw Load	Steam Press. Lbs. Gage	Superheat Degrees F.	Vacuum In. Hg.	Lbs. per Kw-Hr.	Eff. Ratio
750	151.4	99.1	28.01	18.0	56.0

of a design similar to the 3600 r.p.m. turbine of Fig. 20. There were a large number of these built.

*See A. S. M. E. paper by Samuel Naphtaly, December, 1910.

*See the JOURNAL for January '18, p. 3.

1914

Some important machines of 30 000 kw capacity were shipped to the Interborough Rapid Transit Company of New York City, in which the principle of so-called cross-compounding was introduced; the steam expansion being divided in two separate elements, each driving a separate generator. The high and low-pressure element respectively operating at different speeds, each at the nearest synchronous speed most suitable to the steam volume involved, as shown in Fig. 19. The advantage of cross-compounding is commended for the increased reliability thereby gained.*

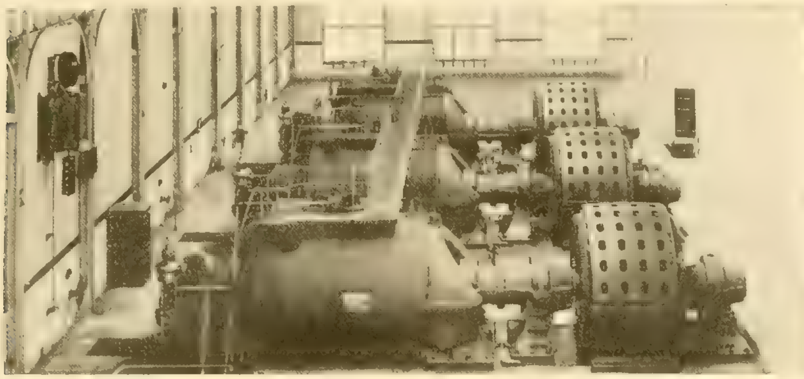

FIG. 15—5500 OR 7500 KW, 750 R. P. M., PARSONS STEAM TURBINE

PERFORMANCE

Kw Load	Steam Press. Lbs Gage	Superheat Degrees F.	Vacuum In. Hg.	Lbs. per Kw-Hr.	Effi. Ratio
9806	177 6	96.0	27.31	15.21	67.4

1915

Machines of 20000 kw maximum capacity, 25 cycles 1500 r.p.m., as shown in Fig. 22, having higher design coefficients than those heretofore built for machines whose expansion was complete within a single cylinder, were shipped in 1915.

1916

A 60-cycle machine of 1800 r.p.m. of similar design to the above was developed in 1916.

1917

During the year, 30 000 kw machines of single-double-flow construction were shipped, having all-reaction blading, the complete expansion being carried out within a single cylinder, as shown in Fig. 25.

Another high efficiency machine of 35 000 kw capacity has been shipped to the Commonwealth Edison Company of Chicago, the steam expansion being divided in two elements like those described under 1903, the cylinders being arranged tandem fashion, and driving one generator, as shown in Fig. 24. The first of these machines has been placed in successful operation during the year.

Some 40 000 and 45 000 kw, 60-cycle, cross-compound machines, similar to the Interborough Rapid Transit Company's machines, have lately been put in service. The high-pressure element operates at 1800 r.p.m. and the low-pressure at 1200 r.p.m. There are also under construction 60 000 kw turbines for both 25 and 60-cycle service, which are a further development of the compound principle, in that the turbine element will comprise one high-pressure and two low-pressure elements, the steam passing through the latter in parallel and each driving separate generators. Means are provided that, should the circuit-breaker open on any one of these elements or should the unit be put out of service by means of the emergency stop, the remaining two units will continue operating, thus providing in a measure the economy commensurate with a very large unit with the flexibility of a number of smaller units.

It is expected that the new 35 000 kw, 60 cycle, 1200 r.p.m., tandem-compound turbine with direct-connected exciter, with a load of 25 000 kilowatts at 85 percent power-factor, at 220 pounds, gage steam pressure, 20c degrees F. superheat and a vacuum of 29 inches mercury, will have a steam consumption of 10.65 pounds per kilowatt-hour, and an efficiency ratio of 75.4.

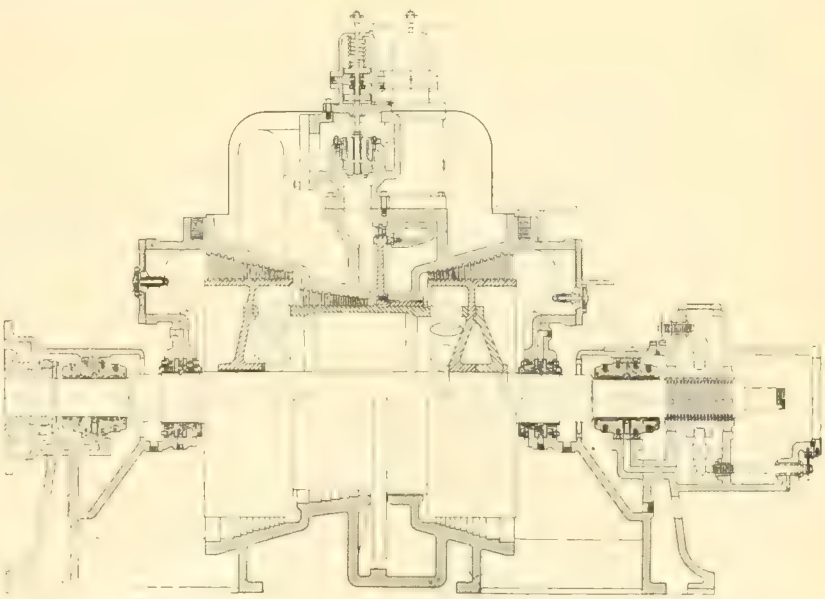

FIG. 16—SECTION OF A 6000 KW, 1500 R. P. M., SINGLE-DOUBLE-FLOW STEAM TURBINE

With a load of 50 000 kilowatts at 275 pounds gage steam pressure, 200 degrees F. superheat and a vacuum of 28.5 inches mercury, the new 60 000 kw, 60 cycle, 1800 and 1200 r.p.m. three-cylinder, cross-compound turbine at 85 percent power-factor will have a steam consumption of 10.65 pounds per kilowatt-hour

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*A complete description of these machines is given in the article on "Efficiency Tests of a 30 000 Kw, Cross Compound Steam Turbine" by Messrs. H. G. Stott and W. S. Finlay in the JOURNAL for July, '16, p. 335.

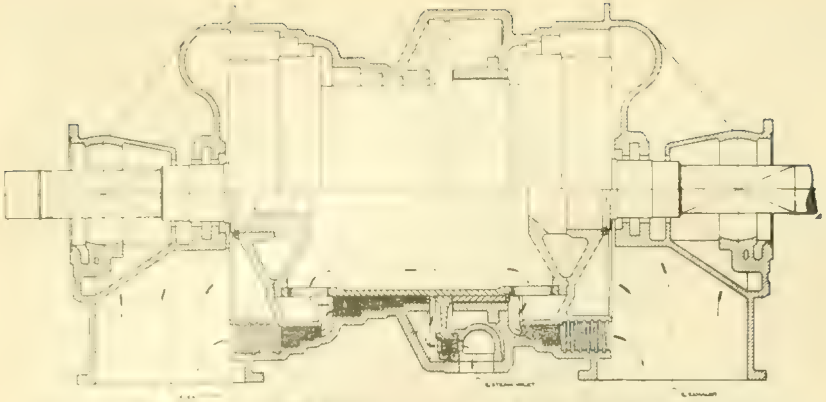

FIG. 17—SECTION OF A 10,000 KW, 750 R. P. M., SINGLE-DOUBLE FLOW STEAM TURBINE

PERFORMANCE

Kw Load	Steam Press. Lbs. Gage	Superheat Degrees F.	Vacuum In. Hg.	Lbs. per Kw Hr	Eff. Ratio
11 466	177.2	106.3	28.13	14.45	66.1

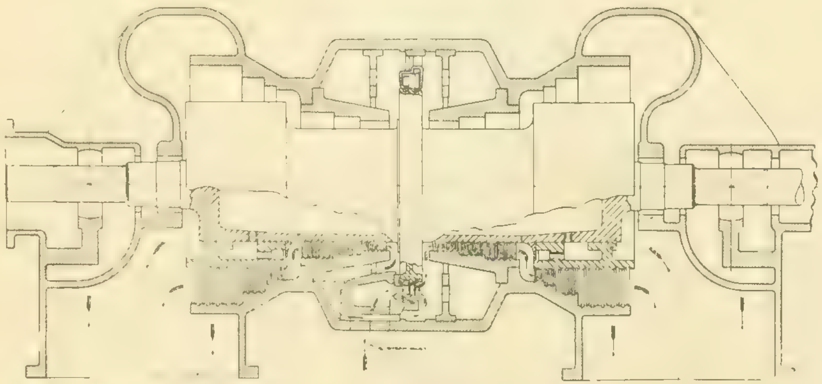

FIG. 18—SECTION OF A 10,000 KW, 1800 R. P. M., DOUBLE-FLOW STEAM TURBINE

Having impluse element single-flow and reaction blading double-flow.

PERFORMANCE

Kw Load	Steam Press. Lbs. Gage	Superheat Degrees F.	Vacuum In. Hg	Lbs. per Kw Hr.	Eff. Ratio
9173	167	59	27.9	14.572	69.0

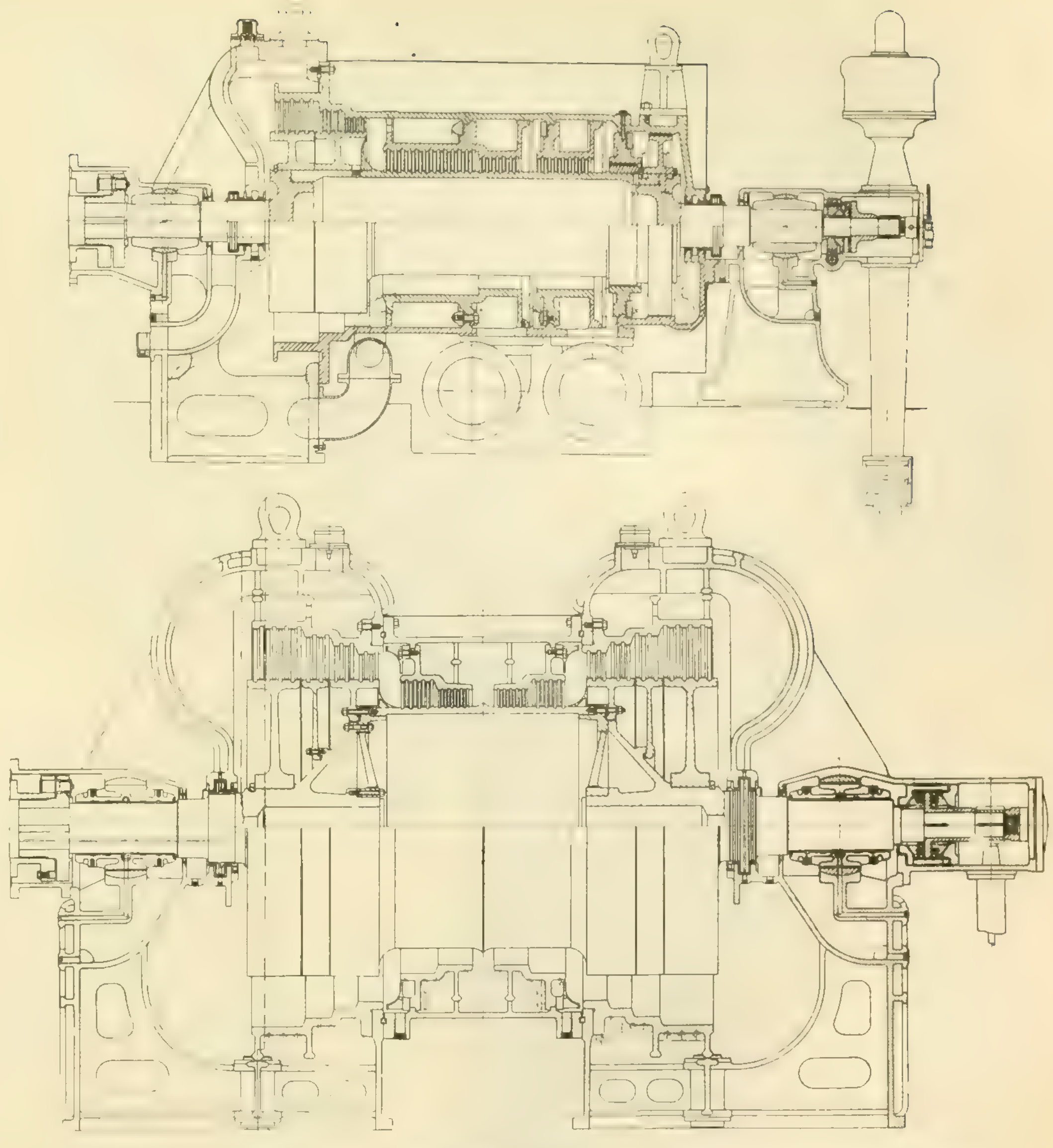

FIG. 19—HIGH AND LOW-PRESSURE SECTIONS OF A 30,000 KW, CROSS-COMPOUND STEAM TURBINE.

PERFORMANCE

Kw Load	Steam Press Lbs. Gage	Superheat Degrees F.	Vacuum In. Hg.	Lbs. per Kw-Hr.	Eff. Ratio
26 740	209	108.5	28.862	11.47	75.51

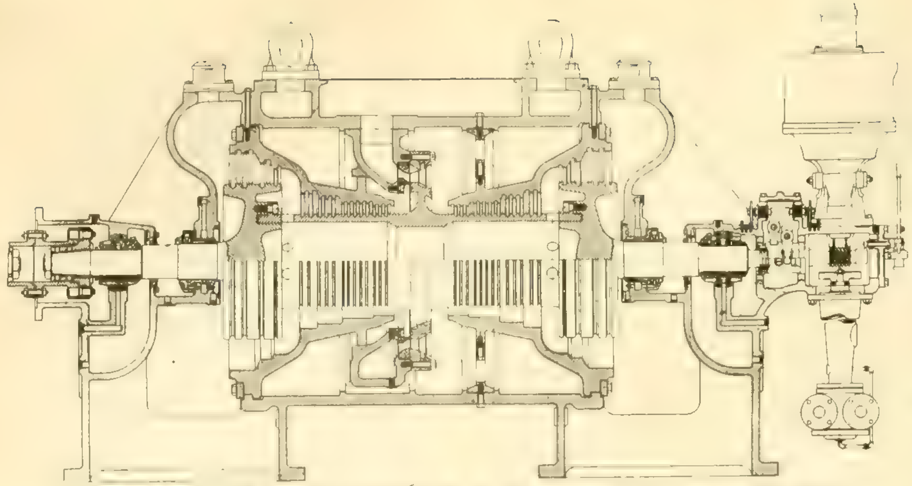

FIG. 20—SECTION OF A 3500 KW, 3600 R. P. M., DOUBLE-FLOW STEAM TURBINE

PERFORMANCE

Kw Load	Steam Press. Lbs. Gage	Superheat Degrees F.	Vacuum In. Hg.	Lbs. per Kw Hr.	Eff. Ratio
3500	175	100	28.5	14.6	64.4

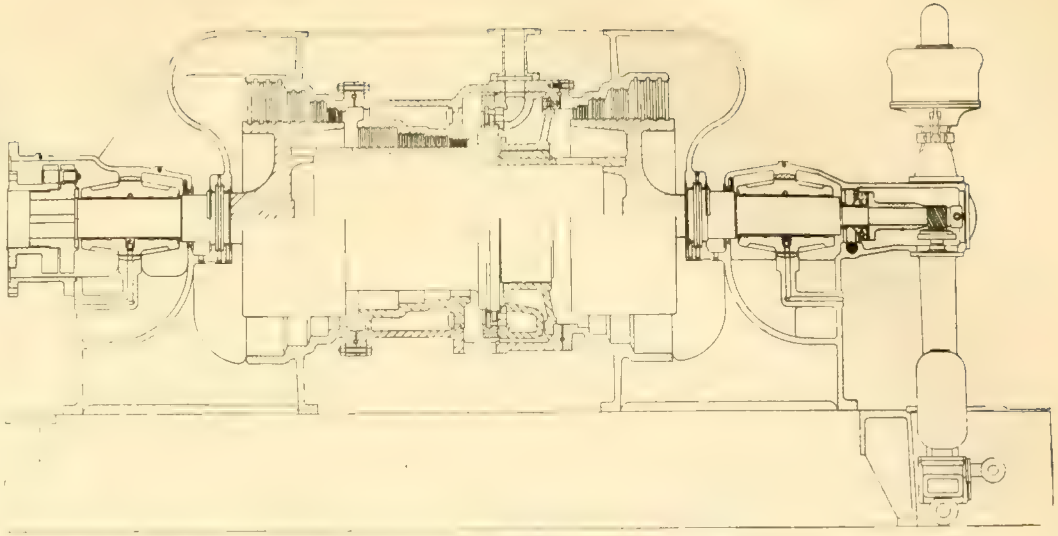

FIG. 22—SECTION OF A 20 000 KW, 25 CYCLE, 1500 R. P. M., SINGLE-CYLINDER TURBINE

PERFORMANCE

Kw Load	Steam Press Lbs. Gage	Superheat Degrees F.	Vacuum In. Hg.	Lbs. per Kw-Hr.	Eff. Ratio
12 122	198.1	127.6	29.01	12.06	69.1

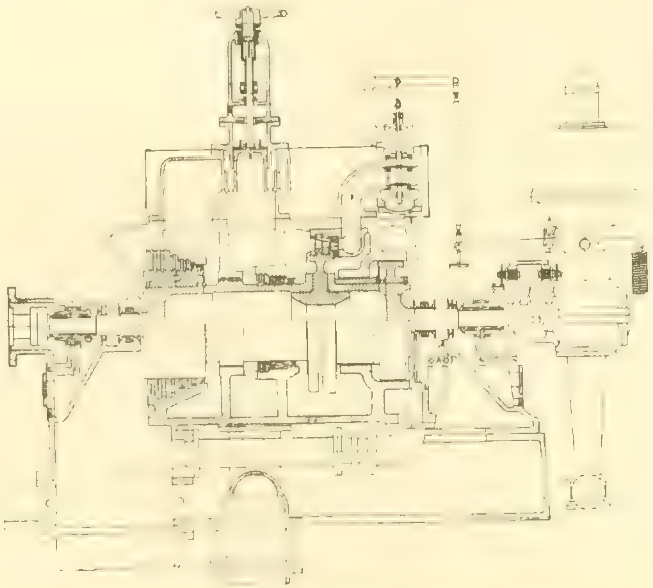

FIG. 21—SECTION OF A 1500 KW, BLEEDER TURBINE

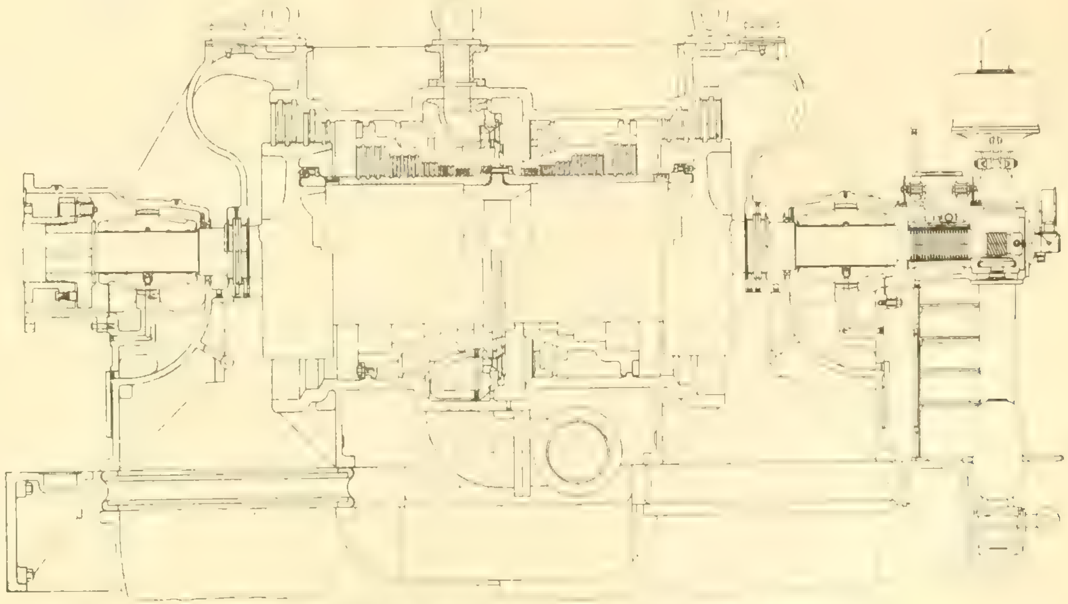

FIG. 23—SECTION OF A 20 000 KW, 1500 R. P. M. STEAM TURBINE

PERFORMANCE

Kw Load	Steam Press Lbs. Gage	Superheat Degrees F.	Vacuum In. Hg.	Lbs. per Kw-Hr	Eff. Ratio
16 061	184.4	99.0	28.50	13.15	70.2

and an efficiency ratio of 76.2. Also the 60 000 kw, 25 cycle, 1500 r.p.m., three-cylinder, cross-compound turbine at 100 percent power-factor with a load of 40-000 kilowatts at 205 pounds, gage steam pressure at 150 degrees F. superheat and a vacuum of 29 inches of mercury, will give a steam consumption of 10.75 pounds per kilowatt-hour and an efficiency ratio of 77.7.

In comparing the foregoing performances, cognizance must be given to the fact that the efficiency ratio cannot be used as a direct comparison, for the same turbine will give a higher efficiency ratio with higher superheat. This emphasizes the quite remarkable performance of the earliest machines. The efficiency ratios quoted in the foregoing include generator losses. It may be proper to explain that by efficiency ratio is meant the ratio of the energy actually obtained from an engine to that which is theoretically obtained by the adiabatic expansion of steam between the specified pressure and temperature limits.

It is interesting to record that owing to the changed condition of the merchant marine in the United States, a large number of vessels are under construction in which geared turbines are being employed. The Westinghouse Company has built and has under contract steam turbine propelling machinery for two hundred and forty-four merchant ships with an aggregate horse-power capacity of 480 000. Four of the above have been to sea and proven eminently successful. In addition to the above the Westinghouse Company has built and has under contract turbine propelling machinery for fifty-six naval vessels aggregating 1 600 000 horse-power. In the case of a 10 000 horse-power passenger ship trading in the Pacific, 22.8 percent gain in fuel consumption is experienced as compared with a sister ship having modern four cylinder, three stage reciprocating engines.

(To be continued)

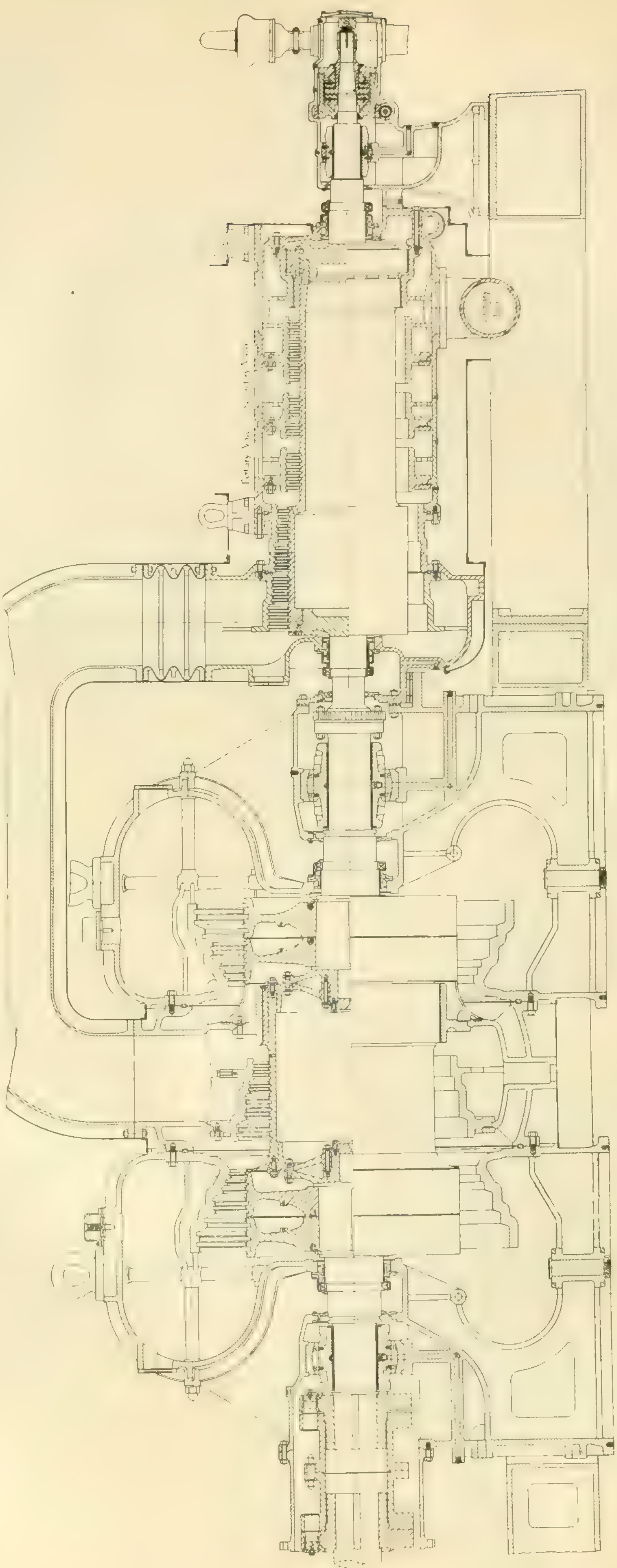

FIG. 24—SECTION OF A 35 000 KW. STEAM TURBINE

The steam expansion is divided in two elements with the cylinders arranged in tandem.

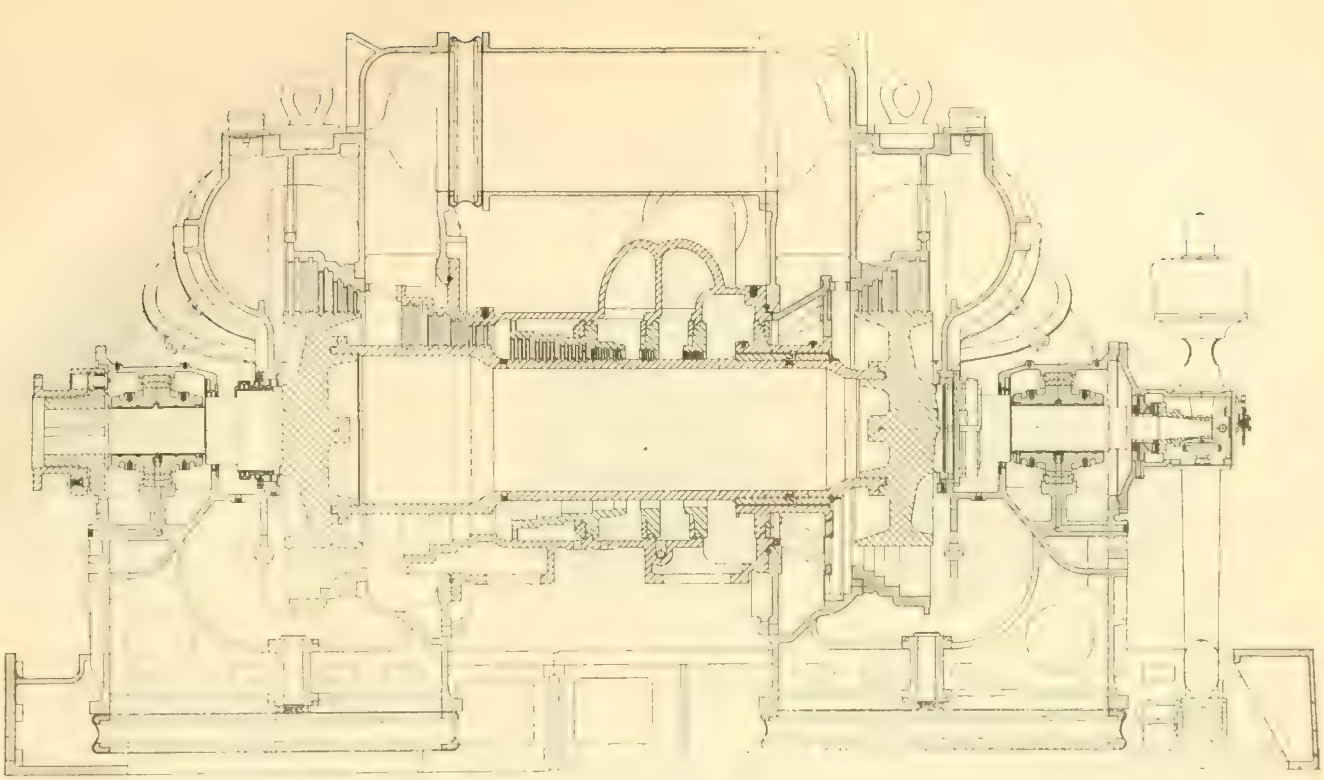

FIG. 25.—SECTION OF A 30 000 KW. SINGLE-DOUBLE-FLOW STEAM TURBINE
Having reaction blading and complete expansion within a single cylinder.

Industrial Controllers-XIV

Machine Tool Controllers

H. D. JAMES and A. L. HARVEY

THE application of motors to machine tools in general divides itself into (a)—constant speed motors and (b)—adjustable and varying speed motors.

CONSTANT SPEED

Some machine tools, such as lathes and drills, are provided with mechanical means for speed change and also mechanical means for reversing. This is particularly true of automatic lathes and screw machines. Another constant speed application is where the motor is belted either to a group of machine tools operating from one motor, or an individual machine. Applications of this type do not require any special features in the controller and the ordinary starters described in the February and March, 1917, issues of the JOURNAL can be used.

Constant speed motors are frequently used for moving the tail stock of large lathes, cross rails, tool carriage of planers, boring mills, etc. These motors are usually of ten horse-power or less and are provided with reversing controllers. The alternating-current and the smaller direct-current motors are connected directly to the line; the larger direct-current motors are provided with automatic acceleration. A common form of controller for this application is shown in Fig. 1. It consists of a drum controller, whose handle has a central position with two positions either side of the center for direct current and for alternating current one position either side of the center, the central position representing the off position, and the position either side of the center connecting the motor to the line for forward or reverse operation. The same arrangement can be used for the smaller direct-current motors. Some are connected directly to the line and others have a fixed resistance in series to reduce the starting torque. It is often desirable to provide dynamic braking in the central position. When this is used, the first position on either side of the center is a drift position, which disconnects the motor from the line but does not apply the brake; the second position gives forward or reverse operation. This switch is provided for connecting accelerating contactors in circuit for direct-current motors, where the size of the motor requires the use of automatic acceleration.

This drum switch is also used for constant-speed motors on small machines where the cutting speed is constant or where the speed can be adjusted by mechanical means. A controller of this kind has a wide application and will be described later in connection with adjustable speed of motors.

ADJUSTABLE AND VARYING SPEED MOTORS

Motors of this class driving machine tools, comprises a wide range of applications. Considerable ingenuity is required to give the desired flexibility of control and at the same time avoid unnecessary complica-

tion. In providing control apparatus for machine tools, it is very desirable to have as many parts as possible interchangeable, so as to minimize the repair parts required, to make it easy for the electrician to understand the control apparatus and make replacements where necessary.

FIG. 1—DRUM REVERSE SWITCH FOR DIRECT-CURRENT DYNAMIC BRAKING SERVICE

The speed of a direct-current motor may be changed in two ways:—

a—By changing the resistance in series with the armature. This is known as varying speed control. The speed of the motor on any notch of the controller depends upon the load on the motor, the light loads giving higher speeds than the heavy loads.

b—By changing the field strength of the motor, known as adjustable speed control. This gives practically a uniform speed for each notch of the controller.

Alternating-current motors are furnished for varying speed only. These motors are of the slip-ring type and have external resistance in the secondary circuit which is changed to vary the speed. The characteristics of control are practically the same as for a direct-current motor with armature control.

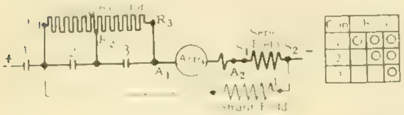

FIG. 3—CONNECTIONS OF NON-REVERSING CONTROLLER PANEL OF FIG. 2.

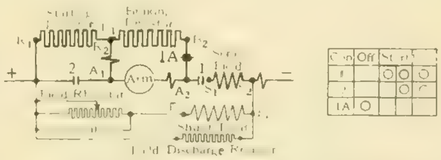

FIG. 4—CONNECTIONS OF NON-REVERSING PANEL WITH DYNAMIC BRAKE

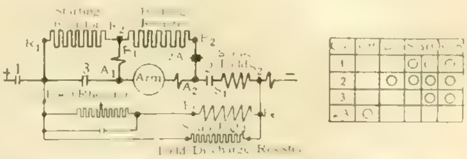

FIG. 5—SAME AS FIG. 4 WITH ADDITION OF DRIFT POINT CONTACTOR

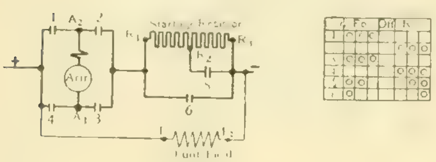

FIG. 6—CONNECTIONS OF REVERSING CONTROL PANEL

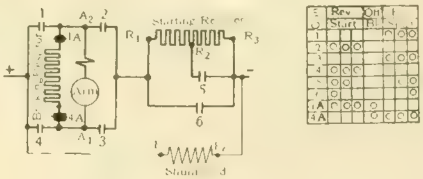

FIG. 7—SAME AS FIG. 6 WITH DYNAMIC BRAKE

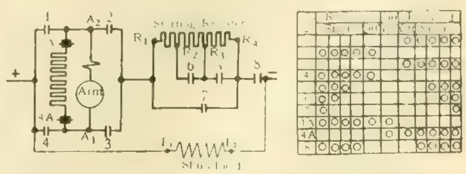

FIG. 8—SAME AS FIG. 7 WITH ADDITION OF DRIFT POINT CONTACTOR

The use of a varying speed motor is uneconomical if the motor is operated much of the time at reduced speeds, as considerable loss occurs in the series resistance. A wide range of speed can, however, be obtained with a less expensive motor than if adjustable speed were used, and for some applications having intermittent service, such as bending rolls, this form of motor is satisfactory. The adjustable speed direct-current motor is the one usually employed where a change in motor speed is required.

A list of the more common magnetic control applications is given in Table I. While the form of control given in this table is not always used with the application indicated, it represents a practical form of control and one that is suitable for most installations. The question of dynamic brake and drift points is governed to a considerable extent by the particular work per-

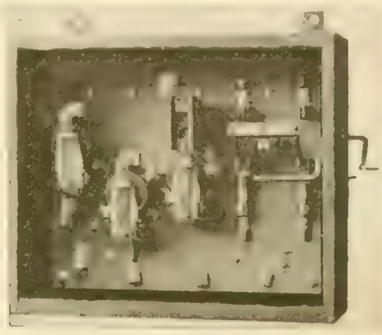

FIG. 2—NON-REVERSING CONTROLLER Mounted in cabinet.

formed by the tool; in some cases, it is a matter of personal preference. Where the motor is small, the controller shown in Fig. 1 can be used and both dynamic braking and drift obtained at small additional expense.

If the control of machine tools be analyzed, the various arrangements may be classified as follows:—

1—*Nonreversing Control Panel*—The wiring diagram of this panel is shown in Fig. 3. It consists of a line contactor and one or more accelerating contactors, together with the starting resistor. The panel should also contain a knife switch and overload protection by either fuses or an overload relay. It is preferable to mount this panel in a cabinet and arrange the handle of the knife switch so that the switch can be opened from the outside of the panel and can be locked in the open position to prevent the accidental starting of the machine tool when the attendant is adjusting or repairing it. This knife switch should be used only for disconnecting, and the motor should be started and stopped with the line contactor. The connections provide for low voltage protection. One of these controllers is shown mounted in a cabinet in Fig. 2.

2—*Nonreversing Control Panel with Dynamic Brake*—The diagram of connections for this control

panel is shown in Fig. 4. It is the same as for the control panel shown in Figs. 2 and 3, with the addition of a back contact, to provide for dynamic braking. The diagram also shows the connections to a field rheostat.

3—Nonreversing Control Panel with Dynamic Brake and Drift—Fig. 5, is the same as Fig. 4, with the addition of a second line contactor to provide for a drift point in addition to the dynamic braking. By opening this extra line contactor, the motor is disconnected from the line on this side and allowed to drift. When the other line contactor is opened, it disconnects the opposite side of the motor from the line and the back contact closes, giving dynamic braking.

4—Reversing Control Panel—This panel, Fig. 6, has four line contactors and one or more accelerating contactors, together with the necessary resistor. It should also have a knife switch and overload protection and should be mounted in a cabinet, as described for the controller under item *1*, Figs. 2 and 3.

5—Reversing Control Panel with Dynamic Brake—This panel, Fig. 7, is the same as Fig. 6, with the addition of a back contact on two of the line contactors. When both the forward and reverse contactors are open, the back contacts establish the dynamic brake circuit.

6—Reversing Control Panel with Dynamic Brake and Drift—This panel is shown by diagram in Fig. 8 which is the same as Fig. 7 with the addition of another line contractor, *8*. This additional contactor is necessary only where the forward and reverse switches are double pole. Where single pole switches are used for reversing the motor, the drift position can be obtained by opening the reverse contactors, *2 or 3*, which are not equipped with back contacts. The opening of one of the reversing contactors disconnects the motor from the line on one side and allows it to drift. The opening of the other line contactor completes the dynamic brake circuit and stops the motor. Since these controllers with reversing contactors are usually applied to large motors, the addition of the extra contactor on the other side of the line is frequently desirable, as it entirely disconnects the controller from the line. This disconnecting is not always necessary, as the opening of the knife switch will effect the same results. The knife

TABLE I—MAGNETIC CONTROL FOR MACHINE TOOLS

This table covers a typical list of magnetic control for adjustable speed direct-current motors, suitable for general application in the average large machine shop. Braking, drift, and arrangement of field rheostat in different combinations form the basis of most machine tool controllers.

Tool	Form	Range in Size	Hp Range	Speed Ratio	Controller	Rev.	Dynamic Brake	Drift Point	Master Switch	Field Rheo.
Lathe	Automatic		3 to 15	2 : 1	Magnetic	No	No	No	Push Button	Separate
	Cut off	1½ to 8 inches	5 to 20	2 : 1	Magnetic	No	No	No	Drum Type	With Master
	Engine	16 to 60 inches	3½ to 20	3 : 1 4 : 1	Magnetic	Yes	Yes	Yes	Drum Type	With Master
	Vert. Turret	24 to 42 inches	3½ to 15	2 : 1	Magnetic	No	No	No	Push Button	Separate
	Horiz. Turret	18 to 36 inches	3½ to 15	4 : 1	Magnetic	No	Yes	Yes	Drum Type	With Master
	Screw Cutting		5 to 15	3 : 1	Magnetic	Yes	Yes	Yes	Drum Type	Separate
	Car Wheel	42 to 90 inches	20 to 50	2 : 1 3 : 1	Magnetic	Emerg.	Yes	No	Push Button	On Panel
Boring Mill	Vertical	30 to 192 inches	5 to 30	3 : 1	Magnetic	No	Yes	No	Push Button	Separate
	Horizontal	2 to 4 Spindle	7½ to 10	4 : 1	Magnetic	No	Yes	Yes	Drum Type	With Master
†Boring Mill**	For Segmental Turning				Rev. Planer	Yes	Yes	No	Planer	On Panel
Milling Machine	Horizontal	18x8x19 in. to 42x14x20 in.	3½ to 15	4 : 1	Magnetic	No	No	No	Drum Type	With Master
	Slab		15 to 75	3 : 1	Magnetic	No	No	No	Drum Type	With Master
Drills	Gang	4 to 6 Spindle	5 to 15	4 : 1	Magnetic	No	No	No	Drum Type	With Master
	Radial	4 to 10 feet	4 to 20	3 : 1	Magnetic	No	No	No	Drum Type	With Master
	Upright	20 to 30 inches	2 to 7½	2 : 1	Magnetic	No	No	No	Drum Type	With Master
	Portable	8 to 16 inches	1½ to 10	4 : 1	Magnetic	No	No	No	Drum Type	With Master
Planer**	Reverse		10 to 75	4 : 1	Rev. Planer	Yes	Yes	No	Planer	On Panel
	Non-Reverse		7½ to 30	2 : 1	Non-Rev. Planer	No	No	No	Planer	On Panel
Shaper	Horizontal	16 to 36 inches	3 to 10	3 : 1	Magnetic	No	*	No	Push Button	Separate
	Vertical	6 to 12 inches	1 to 7½	3 : 1	Magnetic	No	*	No	Push Button	Separate
	Draw Cut**		Special		Rev. Planer	Yes	Yes	No	Planer	On Panel
Saw	Band	48 inches	1 to 7½	2 : 1	Magnetic					
	Cold Toothed.		2 to 25	2 : 1	Magnetic					
	Cold Plate		Up to 200	2 : 1	Magnetic					

†If the shape of the work is such that a number of pieces cannot be put on the table, so the tool cuts at least 40 percent of the time, a considerable increase in production can be obtained by using a reversing planer equipment.
*Dynamic braking desirable where work is changed frequently.
**Cut and return speed.

switch, however, should never be opened under load, and the use of the extra contactor is sometimes desirable to clear a short-circuit, due to a ground. Items *3* and *6* provide for this extra contact, which may or may not be opened in advance of the dynamic brake contactor, depending upon whether or not a drift point is required.

7—Field Rheostat Separately Mounted— This rheostat, Fig. 9, can be used in connection with any control panel to provide adjustable speed control for the motor. It is desirable to have this field rheostat mounted separately from the panel, so that the operator does not have to place his hand near the main control circuit for operating it. It is also convenient to have the rheostat separately mounted so it can be located in a convenient place and the control panel located on the machine tool or the wall where it is not readily accessible to unauthorized persons. Where the control panel is enclosed in a cabinet, the rheostat may be mounted in the cabinet with the handle extending to the outside. This requires the control cabinet to be located in an accessible place and is not convenient for many machine tool applications.

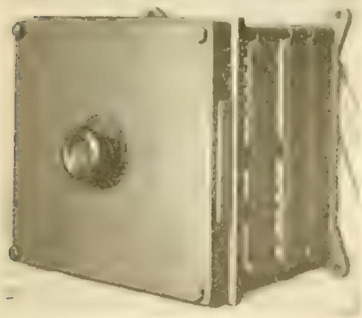

FIG. 9 — SEPARATELY MOUNTED FIELD RHEOSTAT

FIG. 10— COMBINED MASTER SWITCH AND FIELD RHEOSTAT

8—Push Buttons—Push button stations may consist of one or more buttons arranged for manipulating a controller panel. They are usually applied to nonreversing panels and consist of a start and stop button. They may be located close to the field rheostat making a very compact and neat arrangement where the motor is operated for considerable periods of time.

9—Drum Reverse Switch—A small switch is illustrated in Fig. 1. It may be used in connection with nonreversing panels to give reversing control. The same arrangement can be extended to larger switches when desirable.

10—Master Switch and Field Rheostat Combined—This arrangement, Fig. 10 is very convenient for lathes and similar tools, particularly where large motors are used. It is used in connection with one of the panels described in items *1* to *6*.

11—Reversing Switch and Field Rheostat—This consists of a controller for reversing the direction of rotation of the motor, combined with a field rheostat and provided with contacts for operating one of the control panels, items *1* to *3*.

12—Reversing Controller with Field Rheostat—Fig. 11 shows a small controller which is selfcontained and can be used for adjustable speed motors on reversing service. A great many controllers of this type are used for motors up to ten horse-power capacity. It is easy to operate and proves quite durable for these motors. It does not require a controller panel. It is usually connected directly to the line through a knife switch and fuses.

Where adjustable speed motors having a considerable range of speed adjustment are used, it is desirable to provide for starting with full field strength. This can be taken care of in several ways. Where the field rheostat is not mechanically connected to the master switch a convenient method is to use a small contactor for short-circuiting the field rheostat during acceleration. This contactor can be made to operate automatically on a variation of current strength when desirable, but precautions should be taken to reverse the functions of this contactor or relay during regeneration. The relay, however, should short-circuit the field rheostat during dynamic braking. The amount of complication involved in the use of this relay will depend upon the size of the motor. For small motors, a small contactor held closed until the last accelerating switch is closed will be found very satisfactory and will eliminate most of the complication.

The twelve items described above, make a very convenient combination from a manufacturing standpoint, as well as from the standpoint of the user. The control panels, particularly item *1*, can be used for pumps, fans, and many forms of drive other than machine tools. Items *7* to *12* will be found useful for a variety of other applications. A manufacturing establishment requiring machine tool controllers has a great deal of other apparatus operated by motors requiring control. It is therefore desirable to permit the works department of such a company to adopt a few standard controllers which have a more or less uniform application.

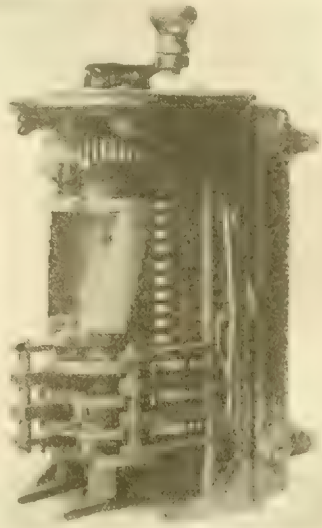

FIG. 11—REVERSING CONTROLLER WITH FIELD RHEOSTAT
Armature starting and field control.

THE JOURNAL QUESTION BOX

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We feel confident that this department will have a still wider field of usefulness, and welcome any and all questions of an electrical or mechanical engineering nature, which are of general interest. (Ed.)

1562—SPEED CHANGES IN INDUCTION MOTORS—Referring to Mr. A. M. Dudley's article on "Reconnecting Induction Motors" in the JOURNAL for Feb. '16, p. 85, with particular reference to Figs. 15 and 17 on pages 90 and 91, instruction and diagrams are given for changing connections to three phase, two speed, four and eight pole operation. Fig. 15 shows the connections for both the four and eight pole operation and we recently tried this on a motor marked 20 hp, 220 volts, three phase, 60 cycles, 1720 r. p. m., the object being to change the motor to eight poles and obtain approximately one-half the rated horse-power. The stator has 48 slots, 48 coils, the coil throw 1 and 13 and was connected parallel star for four pole and was rewound series star for eight pole using Fig. 15 of Mr. Dudley's article. The rotor has 37 bars. After these changes were made the motor would not attempt to start and could not be brought up to speed by mechanical means when the power was applied. Will you kindly let us have your comments as to why this motor would not operate at the low speed? W.T.E. (N.Y.)

There is evidently some misunderstanding on this point, as it was intended in the JOURNAL article to state only that it is sometimes possible to reconnect motors for two speeds in this way. The reason the connection described did not work is because the coils were exactly pitched for the four-pole connection which made them exactly cancel each other in each individual slot when connected for eight-poles. This condition is shown in Fig. (*b*). Fig. (*a*) shows the distribution of the magnetic field around the air-gap of the motor when it was connected for four-poles On account of the throw of the coil being 1 and 13, this winding is exactly symmetrical and the field form is perfectly symmetrical, as shown in Fig. (*a*). The top part of Fig. (*a*) is intended to represent a developed cross-section of the motor winding, showing the conductors for the three-phase as indicated in groups of four. The arrows placed over these conductor groups indicate the direction of the current in the group in the proper three-phase relation at the instant when the value of the *X* phase and the *O* phase is one-half and the value of the current in the — phase is one. Fig. (*b*) shows the condition in which the motor was when connected up for eight-poles. From the arrows it may be noted that the conductors in the tops of the slots carry current which is in phase and

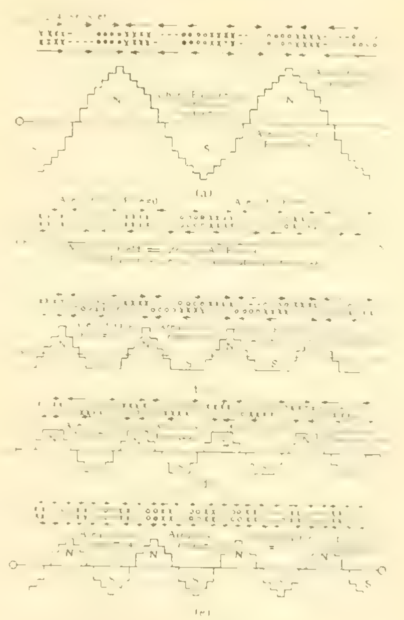


FIG. 1562 (*a*), (*b*), (*c*), (*d*) and (*c*)

exactly opposite in direction to the current in the bottom of the slots. This results in complete neutralization, so that the magnetic field is zero at all points as represented by the straight line. Fig. (*c*) shows the condition which would exist if the throw of coils had been 1 and 9 instead of 1 and 13. An eight-pole field results, but it is not perfectly symmetrical and provided the voltage were reduced to 37.5 percent on the eight-pole winding to what it was on the four-pole winding, the motor would operate properly at an eight-pole speed, and develop about three-eighths of the horse-power rating that it did on the high speed. Fig. (*d*) shows the condition that would result if the throw of the coils had been 1 and 7 instead of 1 and 13, that is to say, if it were exactly pitched for an eight-pole winding. The resulting eight-pole field is perfectly symmetrical, and it could be operated on a voltage about 43 percent of the four-pole voltage and develop a horse-power about in the same percentage. Further interesting facts can be noted from the study of these figures, of which the following might be mentioned. The area under the curve, which represents the four-pole magnetic field can be called 56 for each pole, or $56 \times 4 = 224$ for the complete machine. This area can also be taken to represent the counter electromotive-force which would be developed in the stator winding by this four-pole rotating field. It will be assumed in going to eight poles that the same field strength is to be kept in the air-gap as the stator teeth will probably not stand any higher density. Since the same field strength is to be kept, and the rotating field travels at half the r. p. m., a counter e. m. f. will be generated of only one-half of the value that it had in the case of the four-pole machine. This fact explains why practically all two-speed motors are run with the windings in parallel on the high speed and in series on the low speed. Since the counter e. m. f., which is generated in any individual conductor is only one-half what it was on the high speed, it is necessary to put twice as many conductors in series on the low speed, if the motor is to be operated on the same line voltage. Comparing Fig. (*a*) with Fig. (*d*) it would naturally be expected that the total area under the field curve might be one-half of 224 or 112. As a matter of fact, it measures 96. This difference is due to the fact that the winding is connected for consequent poles, that is, all the pole phase groups have current passing through them in such a direction as to make all north

poles while the south poles are the result of the magnetic field being compelled to find a return path. Another way of expressing this same idea would be to say that instead of actually having 24 pole phase groups, we have only 12, and that any given pole phase group, instead of being spread over the proper arc for the eight-pole winding, is spread over the arc for a four-pole winding. The result of this is to introduce a factor which is called a distribution factor and which reduces the effective value of the magnetic field, and consequently reduces the counter e. m. f., which is developed by this field. This factor in the case of the three-phase machine is 0.866, and if we multiply 112 × 0.866, as noted above, it comes out very close to the value of 96, which was determined graphically. Comparing Fig. (*c*) again with Fig. (*a*) and (*d*) the total area is 0.88, indicating a still further reduction. This is due to another factor called the chord factor or winding pitch factor, and is due to the coils being wound in slots 1 and 9, instead of 1 and 7, as in Fig. (*d*). The effect of winding a coil over-pitch is the same as winding it the same number of slots under-pitch. Or in other words, in a 48 slot, eight-pole combination, the effect of winding the coil in slots 1 and 9 is magnetically the same as it would be if wound in slots 1 and 5. If a coil having a throw or pitch of 1 and 7, as in Fig. (*d*) for eight-poles, be chorded down to 1 and 5, the chord factor for this particular chord will be 0.866. This is determined, as stated in the JOURNAL article referred to, as the sine of one-half the electrical angle spanned by the coil. In this case, six slots, or a throw of 1 and 7 represent 180 electrical degrees, therefore, four slots, or a throw of 1 and 5 will represent 120 electrical degrees. Half of 130 degrees is 60 degrees and the sine of 60 degrees is 0.866, therefore the area under the curve in Fig. (*c*) will be substantially 0.866 × 96 as compared with Fig. (*d*) or it should be 0.866 × 112, as compared to Fig. (*a*) and both of these values will check substantially to the actual area measured graphically, which is 88. Fig. (*e*) is introduced to show the effect of eliminating both chord factor and the distribution factor for the eight-pole connection and the area is substantially 112, as would be anticipated from the foregoing explanation. The conclusion to be drawn from this is that if a motor originally designed for single speed be reconnected for two speeds, its chances of operation are governed almost entirely by the throw or pitch of the coils, and granting that it does operate, the voltage upon which it should be operated, and the corresponding horse-power which it can develop are governed both by the chord factor and the distribution factor.

A.M.D.

1563 — DIRECT-CURRENT GENERATOR — A short time ago we needed a 12 kw motor-generator set. We had a 15 horse-power, three-phase, 1720 r. p. m. induction motor, and tried to get a suitable generator from the manufacturers, but were unable to get immediate delivery. The best we could find was a second hand 15 horse-power, 220 volt, 1675 r. p. m. compound wound motor. When we got this in operation we found that the voltage was only 160, due to the fact that the speed of the induction motor was too low. In order to raise the voltage, we put the fields in parallel-series, and put three 100 watt lamps in series with the field. This brought the voltage up to about 220 volts. The ammeter showed 2.5 amperes. The fields seemed to be taking about half of the wattage, and the lamps the other half. If we put 13 pounds of No. 25 copper wire on the four coils, it should bring the voltage nearly up to normal. This should add about 0.5 ampere to the field current. We have a rheostat for the machine but would prefer not to use it if we can get the voltage near what it should be. Do you think that this would remedy the trouble?

H.D. (MICH.)

The addition of 13 pounds of No. 25 copper wire to the shunt field coils as they are now connected would give a voltage of 220. This, however, would not be satisfactory on account of the over-heating of the coils due to the small size of copper. By putting on new coils using 72 pounds of No. 19 copper wire, 2500 turns per coil, you would get approximately 220 volts. It would be better, however, to use 90 pounds of No. 18 wire, 2400 turns per coil. This would give 240 volts, and by using your rheostat you could adjust the voltage to the desired value. In putting on new coils care should be taken to have the air-gap the same as it is now, *i. e.*, one-fourth inch total gap. If the old shunt coils are disposed of as scrap copper the cost of putting on new coils will be but very little more than the cost of adding wire to the present coils.

L.W.S.

1564 — GROUNDING ALTERNATORS — Will you advise regarding the best practice of grounding generators? In a station there are two 2400 volt generators, 3500 k.v.a. each, which have a single circuit Y-winding. The voltage is stepped up to 35 000 volts. The transformers are connected delta on both sides at generator and receiving ends. The generators are not now grounded and would like to know if they should be. If they should be grounded would it be better to have only one grounded at any one time? Would it also be good practice to put an automatic oil switch in the ground connection, so that in case of ground on one phase, this oil switch would limit the current and, therefore, the damage?

H.L.H. (ME.)

(*a*) With reference to grounding generators, there are two methods. In one of these, provision is made in the grounding rheostats for a nominal value of current, such as 25 amperes, that would be sufficient to operate relays to indicate a ground condition on the system. With these relays, the operator can either open the grounded circuit or apply a ground connection to the particular conductor that is grounded, thus eliminating a difference of potential between the conductor and ground outside the station. (*b*) The other scheme is to provide for a grounding resistance of such a value as to permit sufficient current to flow to open the circuit. For such a condition, the grounding resistance is generally proportioned so that at least twice the current setting of the maximum feeder flows through the grounding resistance. (*c*) It would be an advantage to ground the generators on the system in question, and also to ground the neutral of the high-tension system either through a grounding transformer or, at some future time, through a delta-star connected transformer. The decision as to the number of generators it would be preferable to ground, would depend on the characteristics of these machines. For units having similar voltage characteristics, the variation in the voltage wave form may be such that a considerable third harmonic would circulate in the winding. For such conditions it would be desirable to ground one machine or provide individual rheostats for each machine. (*d*) We do not consider it good practice to put an automatic oil switch in the ground connection, but recommend that a limiting resistance be installed. See also the article on "A Study of Three-Phase Systems" by Chas. Fortescue in the JOURNAL for Sept. '14, p. 461.

F.C.H.

1565 — REWINDING RAILWAY MOTOR — I would like to know what difference it would make in the horse-power and efficiency of a Gramme ring railway armature if I rewind with round wire instead of flat. The armature was wound with 63 coils of strap 0.081 × 0.163 inch, five turns per coil. It is a wave-wound machine, the commutator being back connected. I figured that two No. 12 B & S, double-cotton-covered wires and one No. 13 B & S, double-cotton-covered wire paralleled would be nearly equivalent to the flat wire. I can get five turns of these three paralleled wires in the slot and through the spider. Is there any objection to this scheme?

C.M.L. (UTAH)

If the armature is rewound as stated, the efficiency will be higher, due to the larger cross-section of copper. The horse-power will also be increased slightly through the higher efficiency. The only objection is that the larger cross-section and the shape of the coil will leave less slot space available for insulation.

1566 — REIOLITE — Please inform me about the manufacture of Reiolite which is made of saw-dust and in general of lumber waste, but I do not know if there are any other components, and the manner of making it. Reiolite is used for the construction of floors on steamers, restaurants, etc., in substitution of stone, to which it is similar but lighter, and non-combustible.

M.G. (MEXICO)

There are a number of compositions under various trade names which are essentially the same and used for floors, wainscoting, etc. Reiolite appears to be one of them. Marbeloid is another. In general they are made up of wood fibre or saw-dust with about an equal proportion of silica, *i. e.*, very finely ground quartz sand cemented together with what is known as magnesium oxychloride cement. There is usually a little clay present in the composition and some chalk with perhaps some other material, such as red oxide of iron for coloring purposes. These materials in general stand up fairly well indoors, but as a rule are not suitable

to withstand weather conditions. A sample analysis is as follows:—

H_2O — Water	8.70 %
Wood Pulp	29.51 %
SO_2 — Silica	21.13 %
Al_2O_3 — Clay	0.83 %
Fe_2O_3 — Iron Ox.	5.70 %
Ca O — Lime	2.37 %
Mg O — Magnesia	23.04 %
Mg Cl_2 — Magnesia Chloride	8.67 %

R.P.J.

1567—Magnetic Qualities of Manganese Steel—What are the magnetic qualities of manganese steel used for the wearing parts of rock crushers, steam shovel dippers, etc.? How does its permeability compare with carbon steels of like hardness?

C.C.C. (ARIZ.)

The magnetic quality of high manganese steel used in rock crushers is very poor. In most cases it is almost non-magnetic. The permeability of steel falls off progressively with increase of manganese and becomes non-magnetic between 11 and 14 percent. High-carbon steel has much higher permeability than this type of manganese steel. It also has a wide hysteresis loop and considerable permanent magnetism. L.W.C.

1568—Parallel Operation of Belt-Driven Alternators—It has been proposed to belt-drive two three-phase, 440 volt generators (one of 250 k.v.a., 600 r.p.m. and the other of 200 k.v.a., 720 r.p.m.) from the same line-shaft, obtaining the correct speeds by proper pulley sizes. As it is desired to combine their outputs by parallel operation at the switch-board, the following questions suggest themselves:—After synchronizing, would not one machine gradually lead the other (due to variable belt slip, non-exactness of pulley diameters, etc.) thus causing corrective currents to flow, resulting in surges between machines, possibly causing the circuit-breakers to open? How would it be possible to secure load-adjustment on either machine, when their relative lag or lead is non-adjustable?

S.G.P. (WASH.)

There should be no difficulty in paralleling, providing reasonable care is taken to obtain correct pulley ratios and attention is given to belt tension. Assuming the machines to be synchronized, and the conditions just named to be met, one alternator would not gradually lead the other. Any advance in phase of one machine ahead of the other would be followed by an increased load on that machine; the increased torque would cause greater belt slippage, and result in the machine settling back to its normal relative phase position. While it is conceivable that some influence might throw the alternators slightly apart in phase momentarily and result in oscillations about the mean position, such oscillations would die out very quickly on account of the powerful damping action of the belts. Cumulative surges of current between the machines are, therefore, not to be expected. Regarding the adjustment of the load division between the two alternators, the only way this can be done is by varying the belt tension. Such adjustment may be required to some extent, because of difference in the belts; for example, changes in the weather may affect the two belts unequally.

F.L.M.

1569—Alternating Current and Direct-Current on Same Circuit—Is it possible to run direct-current and alternating-current banks of lights on a three-wire circuit at different voltages as shown in Fig. (a), both banks of lights being lighted at the same time, if neither side is grounded?

A.B.S. (MINN.)

It is possible to operate lights from a circuit as shown in Fig. (a). You must not consider, however, that this is an ordinary three-wire circuit and hence that the neutral can be of smaller wire than the outside lines. The current in

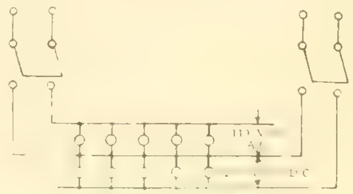


FIG. 1569(a)

the middle wire at any point will be equal to the square root of the sum of the squares of the direct-current and the r.m.s. or effective value of the alternating-current. The actual current capacity at any point could be determined from this rule and from the number of lamps which would be fed by the wire on each circuit at any particular point. L.W.C.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

FEBRUARY 1918

Railway Motor Bearings

Railway motor bearings are of the ball, roller or sleeve type, the latter having been used almost entirely in the past.

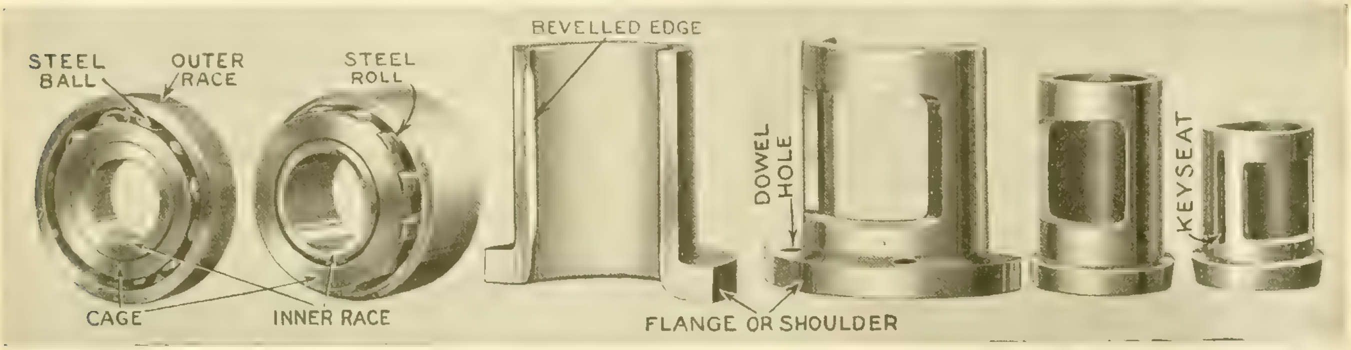
BALL BEARINGS

A ball bearing consists of a train of hardened steel balls, equally spaced by a cage and mounted between inner and outer hardened steel races. The inner ball race is forced on the journal with a light press fit while the outer race engages the housing bore by merely a "sucking" fit. As the journal turns the balls rotate, making a *point contact* on the inner and outer hardened steel races. The inner race should not turn on the journal while in general it is considered desirable for the outer race to crawl in the housing seat, to distribute the wear, due to the balls, uniformly over the ring.

ROLLER BEARINGS

Roller bearings are similar in construction to ball bearings excepting that instead of balls, a train of hardened steel rollers is used, forming a *line contact* with the hardened steel races.

Both the above types of bearings are packed with a grease or lubricated with oil to reduce friction. When properly lubricated and protected from dust and dirt, both starting and running friction are reduced to a minimum and it is believed such bearings will give a long life in service, requiring little attention, providing they are not damaged mechanically.



Ball Bearing for Commutator End — Roller Bearing for Pinion End — Upper Half of Axle Bearing — Lower Half of Axle Bearing — Pinion and Commutator Ends of Sleeve Type Armature Bearing

SLEEVE BEARINGS

A sleeve or plain bearing can be either a split or solid cylinder of a hard metal lined with babbitt, or a split or solid cylinder of babbitt or bronze material not lined. It should have enough clearance over the journal to allow a thin film of oil to form between the journal and the bearing to float the journal. With this type of bearing the running friction is reduced to a minimum, if the film of oil is constantly maintained and is free from dirt, although the starting friction is comparatively high. The bearing will last for a number of years if it is not damaged mechanically. As this is the type of bearing most commonly used it will be described in detail.

Construction—To allow bearings to be removed without taking off the pinion most of the older motors are provided with split armature bearings at both the commutator and pinion ends. Due to improved lubrication, with a resulting increased life of bearings, all modern motors use solid bearings at both ends. This gives a much better mechanical design, which does not require frequent renewals. The pinion end bearings are always larger than those on the commutator end.

Axle bearings are always made in two halves, so they can be removed without taking the gear and wheels off the axle. The commutator end and pinion end bearings are of the same size and in the modern box type motors are interchangeable.

Material—The most common types of armature bearings are made of either a bronze, or a malleable iron shell lined with babbitt. The babbitt lining of a bronze shell is less than the single air-gap in thickness, so as to save the armature core from rubbing on the pole pieces, should there be excessive wear, or the babbitt melt out of the shell due to a hot bearing.

Depending primarily upon the size of the axle and the size of the axle bearing seat in the motor frame, axle bearings are made of either bronze tinned or malleable iron lined with a soft alloy. Other factors, such as first cost, cost of repair, and the experience of the operating man enters into this selection.

Babbitt metal used to line railway motor bearings consists either of a tin base or of a lead base alloy; in other words the bearing metal should be an alloy composed of at least 80 to 90 percent tin or lead respectively. Both classes give good service if properly handled during the melting and pouring process.

Finishes—Where large numbers of bearings of the same size are used, sufficient to support the expense of special tools, the surface obtained by broaching will be found most satisfactory. With most operating companies it is the common practice to machine armature bearings after re-babbitting. Some master mechanics consider this unnecessary and babbitt their bearings to exact size. Whichever method is used, it is customary to scrape the babbitt to get a uniform bearing surface.

Axle bearings, when not lined with babbitt, are given a machined finish and this surface is tinned to fill up the small irregularities thus helping the bearing seat itself while new. Some operators do not consider this tinning necessary. When axle bearings are lined with babbitt they should be machined to get best results in service, although it is the practice of some operators to babbitt to exact size and fit by scraping.

Method of Holding—In addition to a press fit of from three to five tons, keys are most commonly used to prevent the armature bearings from turning in the housing. Most of the older motors without housings have their bearings held from turning by means of a dowel in addition to the clamping action of the frame. Depending largely upon the size and location of the lubricating openings, axle bearings are held from turning by a dowel or a key, as well as by the clamping fit of the axle caps. Dowels in the flange or shoulder of the bearing shell are being used successfully in the more modern motors. Special forms of lugs cast on the bearings, or the use of plates inserted between the two halves of the bearings, have given satisfactory results in service, but are difficult to manufacture.

Windows—The size and location of openings in the bearings for lubrication depend upon the method of lubrication and upon the distribution of the pressure between the journal and bearing. It is desirable to locate these openings or windows at the point of least pressure to permit the feeding of oil between the journal and the bearing.

Clearances which are considered good practice for railway motors using grease, or oil waste lubrication, are:—

Up to and not including 3.5 inches.................0.006 in. min. to 0.008 in. max.
From 3.5 up to and not including 4 inches ...0.008 in. min. to 0.012 in. max.
From 4 inches up to and including 7 inches ...0.012 in. min. to 0.016 in. max.

Oil Grooves—Oil grooves are machined, cut or moulded in armature bearings so as to help the oil to enter and more evenly distribute itself throughout the bearing. In general they are not required in the case of axle bearings, on account of the slow speed and low pressure. The sharp edges at the split of axle bearings should be beveled to prevent wiping away of the oil film by these edges, but this bevel should not extend to the ends of bearings as it would drain off and waste too much oil. It is good practice to round off or bevel the edges of the windows in both armature and axle bearings to encourage the flow of oil into the bearing surface.

THE ELECTRIC JOURNAL

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Black vs White Coal

The time will undoubtedly come when a differentiation will be made between those natural resources of the country which are practically inexhaustible and those which, once used, are gone forever. Our coal supply is of the latter classification—only a certain amount exists in the surface of the earth. Each ton consumed is irreplaceable and any that is wasted or left in the mine when it is abandoned is lost to future usefulness. Coal, therefore, is a natural resource which should be consumed with the limitation of its temporal character well in mind. Its use is a matter in which the government should take a watchful interest.

"White coal" on the other hand is self-perpetuating. The water is lifted by natural forces continually, after which a hydraulic power installation constitutes merely a convenient means of allowing the force of gravity to exert itself usefully. There is no exhaustion of the supply through continuous use and no virtue is taken from the water by making it pay toll in the form of useful work. Likewise nothing is conserved to posterity by allowing water to flow freely from the mountains and the lakes to the sea.

Why then should we go on using up black coal with white coal within easy reach of power users. With a possible 55 000 000 horse-power of undeveloped water power in the United States, with a maximum of 6 000 000 horse-power available at Niagara Falls alone, after liberal discounting for developments not feasible, one does not need to be much of an engineer to realize that enormous savings in coal consumption are possible. Thus, if Niagara Falls were fully utilized, it is estimated that one million tons of coal would be saved annually.

Under present conditions, the use of coal for power involves more than the burning of the fuel in power plants—there is a sort of pyramiding effect. The coal must be dug from the mines, which involves coal consumption, it must be transported, usually in cars, involving still further coal consumption, and the locomotives and cars must be built for the purpose, which necessitates more coal for manufacturing railway equipment, since every ton of steel requires a ton of coal for its manufacture. On the other hand, hydroelectric power can be used to operate railways, thus eliminating a further unnecessary consumption of coal. Again, the consumption of coal which might be saved by use of the water power also takes up the energies of men all along the line who might be more usefully employed in other lines of work.

When it comes to the economics of power generation, which govern largely in ordinary corporation procedure, there is a mistaken impression, as explained by Mr. Townley in this issue of the JOURNAL, that water power *per se* is cheaper than steam power. This is an impression that will not hold water, generally speaking. The probable economic success of a hydroelectric development is dependent upon the relation of its costs to those of a corresponding steam supply. If its total costs are materially lower than for steam, investors may look on it with favor; but if the margin is quite small, experienced investors will be likely to recall that steam economics have improved enormously in the past fifteen years and that the end of such improvement has not yet been reached. In fact, it might very easily be the case that a hydroelectric plant, installed fifteen years ago with some apparent saving over the then-existing type of steam plant, might, in competition with a present day steam plant, be operating at a decided disadvantage. All of these factors should be given adequate consideration in formulating a broad general policy, looking towards the full utilization of our hydroelectric possibilities.

Motor Made Clothing

Standardization of clothing—it is a unique idea. Nevertheless standardized clothing could undoubtedly be produced at less cost than is possible with the bewildering variety of models now offered; and a consideration of the idea, as pointed out by Mr. W. H. Easton in this issue of the JOURNAL, affords a clearer insight into a business, large in the aggregate, which has been almost entirely passed by in the present-day tendency toward the combination of small plants into a few huge factories.

As a result of the extreme diversity of output throughout the clothing business and the consequent multiplicity of relatively small shops all working along the same general lines but producing different models and styles, it has been necessary to apply to comparatively small establishments the same manufacturing methods which have minimized production expenses in the larger factories. This is exclusively the field of electricity. The application of power to such small units by any other means is impracticable from the standpoint of both initial and operating costs, safety, cleanliness and noise. The supplanting of the sweat shop by the modern light, cleanly and well-ventilated shop, with its relatively easy labor is only possible because of the motor-operated sewing machine, the ventilating fan, the electric iron and the electric lamp.

The Hydroelectric Situation Up to Date

Calvert Townley
Assistant to the President
Westinghouse Electric & Mfg. Co.

NOTWITHSTANDING marked improvements in the design and construction of high-voltage long-distance transmission lines and in spite of other advances in the art which have made commercial the transmission of power over longer and longer distances, for a period of ten years that branch of the electrical industry has lagged far behind others. The substitution of water for steam power would, of course, conserve coal and would also release for other uses the labor which mines that coal and the extensive transportation equipment, including the labor operating it, now occupied by such coal. In the midst of a coal famine and of what may later turn out to be a labor famine, to say nothing of insufficient railroad facilities, these facts naturally acquire greatly increased importance, and it may be interesting to inquire the reason why more water powers are not being developed and to analyze some of the conditions.

Broadly, it is fair to say that two principal causes, each quite distinct in itself, are largely responsible for the existing stagnation. One is the very great improvemen in the efficiency of steam prime movers and the reduction in their first cost, and the other is the burdensome conditions imposed by existing Federal laws. The maximum price at which hydroelectric power may be sold is usually fixed, not arbitrarily by any State or Federal Commission but quite naturally by the cost of the equivalent steam electric service. Further, as hydroelectric power carries the hazard of interruption by drought and lightning in summer, ice in the winter and floods in the spring, and as the operation of a long transmission line may introduce serious voltage fluctuations, it is fair to say that such power is inferior to that furnished by steam in every particular except cost so that in order to prevail against competition, hydroelectric power must not only meet the cost of steam electric service, but it must be cheaper.

The operating and maintenance cost of the generator room of a modern steam plant is fairly comparable with that of a modern water power plant and, while a too broad generalization might lay itself open to accusations of inaccuracy, it is perhaps not far wrong to say that the operation and maintenance cost of a boiler room, omitting fuel, is likewise fairly comparable with the cost of that of the hydraulic part of the development and of patrolling, operating and maintaining the transmission lines. In comparing the total costs of the two kinds of power, therefore, we may set up the cost of fuel on one hand against higher fixed charges due to a greater investment on the other. The cost of fuel per kilowatt-hour output, of course, will vary over a wide range, even in the most modern stations, depending on the size of the units installed and the load factors. The fixed charges per unit of capacity of a hydroelectric system vary over a still wider range due to the obvious topographical differences between different power sites and their distances from their markets. A fair average statement would be that the total cost of a hydroelectric system per unit of capacity is from two to five times as much as that of a steam electric development of corresponding size. To get some concrete figures for purposes of illustration, assume for coal costs a maximum of $4.00 and a minimum of $2.00 per short ton, for steam duty a maximum of three pounds and a minimum of 1.5 pounds per kilowatt-hour output and that the plant or output factor varies between the limits of 30 and 50 percent. Under these assumptions, the cost of coal per year per unit of installed capacity will vary between the limits of $26.28 maximum and $3.94 minimum and with the assumptions made, therefore, these coal costs indicate the limits of additional fixed charges beyond which a hydroelectric system cannot go and compete.

In the light of the foregoing, if the total fixed charges, interest, taxes, insurance and amortization fall between the limits of 10 and 15 percent, the corresponding excess first costs of the hydroelectric system over those of corresponding steam plants must come between a maximum of $262.80 and a minimum of $26.27. A hydroelectric system which will cost not more than $26.27 per kilowatt capacity over that of an equivalent steam system is so rare that it may be said to be practically non existent, while on the other hand many such installations if built would exceed the upper limit of $262.80. In such cases the water development becomes a commercial prospect only if the cost of coal for competing service be higher or the prospect of a greater output factor be reasonably certain or if some other operating or maintenance condition be more favorable. Lest any one be confused by the introduction of concrete figures into an abstract discussion it is repeated that they are for purposes of illustration only and, while believed to represent not unusual conditions, are not put forward in any sense as ultimate limits.

It should be borne in mind that I am referring to pre-war conditions and that fifteen years has seen the cost of the steam electric plant divided by three and its thermal efficiency increased by 50 percent. Steam power, therefore, is now a much more dangerous competitor than formerly and many water developments which might have competed against steam in 1900 cannot prevail against its reduced cost today. There is every indication that improvement will continue and that the cost of producing steam power will keep on falling in spite of the ever-increasing price of fuel.

All these facts make it necessary to scrutinize even more carefully than ever, each hydroelectric possibility because, while there are of course many undeveloped sites which when properly treated would yield handsome returns, the only way to separate the meritorious from the commercially impracticable projects is by the most careful and thorough expert examination. As I have often stated in the past, the more I study water power, the greater respect I have for steam.

There is a wide-spread deep-rooted conviction in the minds of the general public that because falling water itself is free, electric power generated from such falling water similarly costs little or nothing to the producer and therefore any one who can acquire possession of a water power site is in a fair way to make his everlasting fortune. Some nine years ago the then Secretary of the Interior withdrew from entry a large number of water power sites on the public domain and revoked permits previously granted for the development of other sites, many of which had been developed and were in operation. The intent of this action, clearly shown in the order of revocation, was to reissue corresponding permits upon terms more advantageous to the Government. If one Secretary could do this, obviously succeeding Secretaries might continue to repeat the process indefinitely and the action therefore caused much consternation and effectually dispelled the previous feeling of confidence that permittees need not fear the revocable clause. To make this situation clear it should be stated that a permit to develop water power on the public domain may only issue, subject to revocation, without reimbursement by any Secretary of the Interior. An investor, therefore, has no assurance that the usefulness of his property may not be destroyed over night. Inasmuch as 70 percent of the undeveloped water power in the United States is in thirteen western states where over two-thirds of all the land itself is owned by the Federal Government, the effect of this revocable requirement in deterring capital from seeking investment in hydroelectric projects becomes apparent. In the case of a navigable stream, the law prohibits construction without a special act of Congress for each individual development. While this has been done occasionally, the task is appalling to contemplate and the net result has been practical stagnation.

It is not disputed that private sources must be relied upon for the capital needed to construct hydroelectric systems. It is no longer seriously contended that existing law is adequate and, as is well known, remedial bills have been introduced into every session of Congress for many years. These facts are encouraging but there is still a grave danger that a law may be enacted which, while expected by its proponents to accomplish the desired result, in reality will not do so. The basic trouble arises from the above named mistaken conviction that water power development and operation are unduly profitable and that the general public as owners and a section of them as power users offer a tempting field for exploitation by monopolistic promoters. There are undoubtedly water powers sufficiently favored where unrestricted financing and unregulated power rates would afford opportunity to do this and greedy promoters might take advantage of such conditions. There are unscrupulous men in all walks of life, even sometimes in the Government service, as witness the advantage taken of a technicality to require the railroads to transport the enormously greater bulk of parcel post matter without any additional compensation whatever. But to throttle and practically stop the use of a natural resource like water power through inability to devise means for preventing abuse is a confession of incompetent stewardship and presents a spectacle of disturbing inefficiency which is discouraging to contemplate.

Coal is another natural resource. Suppose the Government were to say that, because coal barons had profited unduly, no one might mine coal except under impossible financial restrictions. The example is not so very different because the latent energy in one-half of the undeveloped water power now being wasted would supplant at least 126 000 000 tons of coal per year.

In the matter of hydroelectric power on the public domain, the Government is in the position of seeking to have its resources developed without contributing either its capital or credit. It would be unfortunate if the Government should be put in the position of bargaining with capital and of offering just sufficient incentive not to induce investment, so that the present condition of stagnation would continue. The fundamental requirements of capital are security and profit. The greater the security the more numerous are the sources of supply and the lower the rates demanded. That is to say, the project becomes more of an investment and less of a speculation. Lower rates are reflected in the cost of power and therefore stimulate its use. The greater the profit the more easily may money be secured and the greater the incentive to accelerate expansion. The people through the Government desire economical and rapid development, good service and low rates. Security of investment is enhanced by economic development and good service, while low rates attract customers, increase demand and hasten extensions. All of these desiderata—on both sides—go hand in hand. There is nothing antagonistic between any two. The best protection for the investor is full information, and our regulatory commissions long ago devised accounting methods and now regularly require sworn reports of assets and liabilities which are ample. These same commissions afford abundant protection to the power user against extortionate rates. Once a power enterprise is successfully established, it is to every one's interest that it be continued indefinitely. Any provision for future possible interruption by confiscation or recapture operates as just so much of a hazard to the investor which is reflected in an increased power rate.

I regard both the economic and the legislative conditions as fraught with grave dangers to the extensive use of our undeveloped powers. Construction costs are rising—money rates have advanced and the demands for improved service are becoming more and more exacting as against a steadily declining cost of power and a constantly improving service from competing prime movers; while even those who have striven most valiantly to correct existing legislative faults have been induced by the arguments of expediency to yield point after point until, even should their full present requests be granted, the resulting law will fall far short of that which would bring about the maximum possible benefit to our country.

Electricity in Garment-Making Factories

William H. Easton

THE garment-making industry, while by no means the largest in the United States, is nevertheless among the most important, for it comprises about 25 000 factories, gives employment to over 600 000 people and produces annually several billion dollars worth of goods. It is, therefore, sufficiently large to be of interest to both the central station and the electrical manufacturer. But in addition to its mere size, there is another reason why this industry forms an especially good field for the sale of electrical equipment and current, in that the electric motor is the only practicable drive for the sewing machine, which is the basis of the industry. Foot-power has long been abandoned and engine drive is unsatisfactory owing to the complication of belts it involves. Indeed, the use of exposed belts in garment factories is forbidden by law in several states, in the interest of safety to the women workers. The horse-power requirements per factory are not large, five horse-power being the average motor installation, but since each factory requires also a number of lights, several pressing irons and cloth cutting machines, and usually some electric fans, the total load is very satisfactory.

FIG. I—POWER TABLES IN THE SEWING ROOM OF AN EMBROIDERY AND CHILDREN'S CLOTHING FACTORY

Each table is driven by a slow-speed alternating-current motor with a double extended shaft.

CONDITIONS OF THE INDUSTRY

Garment-making factories are those that cut up cloth and sew it into desired forms, as in the manufacture of suits, coats, dresses, waists, skirts, shirts, collars and cuffs, neckwear, corsets etc., but not including those making knit goods, shoes, hats, and other articles which are produced by quite different processes. On the other hand, the manufacture of tents, awnings, sheets and pillow-cases, casket trimmings, window-shades, and umbrellas is closely related to garment making, since these industries are likewise dependent on the sewing machine and present similar manufacturing conditions.

All this work is, in general, highly specialized. There are a few large factories that manufacture a number of different articles, but as a rule each establishment devotes itself to a single item, such as petticoats, children's rompers, or even button-holes. It is for this reason that the average horse-power per installation is so small.

Heretofore the garment maker has been chiefly concerned with problems of design. Novelties and changes in fashion have been the life of the trade and the best insurance for a successful season was to be the first to strike a popular note. But the war has had its effect here, as elsewhere. The present enormous output of uniforms, which must be of good quality but produced as rapidly and as cheaply as possible, has introduced new manufacturing methods, and at the same time economic conditions are tending towards standardization of clothes for civilians. Whether or not such garments will be generally acceptable is uncertain, for from time immemorial people have insisted on individuality in their wearing apparal. At all events the garment maker will have to pay considerably more attention in the immediate future to problems of economical production. Should standardized clothes actually come into general use, it will mean the disappearance of the thousands of small garment factories and the concentration of the bulk of the production in the hands of a few large organizations, as is the case with most goods not affected by style changes.

MOTORS FOR SEWING MACHINES

Almost every operation in the production of a garment requires a sewing machine of special design, so that there is an astonishing variety of models on the market. One manufacturer, for example, lists 29 different machines for use in making men's clothing, while the complete line comprises nearly 400 models and over a thousand modifications of these models. Moreover, models are being added more rapidly than they can be cataloged, since every new kink and wrinkle imposed by fashion is the signal for the development of a new machine. But however much these various models may differ from each other in function and appearance, there is rarely much change in their fundamental principles, so that in spite of their great variety, sewing machines present no such complex problems of drive as are, for example, encountered with machine tools.

As far as drive is concerned, sewing machines can be divided into two classes; those mounted on long

tables called power tables and driven in groups, and those driven individually. In general, machines for light goods are grouped and those for heavy materials, such as duck, burlap, and leather are driven individually.

MOTORS FOR POWER TABLES

The character of the power table is shown in Fig. 1. The sewing machines are generally arranged in two rows and driven from a line-shaft running underneath the table. The length of the table, and therefore the number of machines on it, varies with different factories, but depends mainly on the size of the room and the space desired between cross aisles;—25 machines per table is usually the maximum. Each machine is belted to one half of a friction clutch and the other half is belted to the line shaft. The clutch is controlled by the pressure of the foot on the treadle and since the firmer the pressure the greater the friction in the clutch, a very satisfactory method of speed control is thus provided. Each table is an independent unit with its own line shaft and motor.

FIG. 2—SEWING ROOM OF A SKIRT FACTORY
General lighting is provided by the ceiling drops, and individual lighting by a table lamp with special reflector for each four machines.

The line shaft, which turns at a constant speed of 450 r.p.m. can be driven in three different ways; *1*—by a belt, *2*—by a chain and *3*—by a direct-connected motor. Belt drive, though used in some instances, must be regarded as impractical. If the motor is mounted on the floor with the belt horizontal and at right angles to the table, an awkward arrangement results which takes up a great deal of space and blocks the aisle. Though not impossible for use in a factory with a single table, this method cannot be considered where there are several tables. Nor is vertical belting an improvement, because of the excessive slippage with even an extreme amount of belt tension.

The use of a vertical silent chain with the motor mounted on the table is, however, practical and is employed in a number of factories. The chief advantage of this method, as compared with direct-connection, is that it permits the use of a standard 1100 or 1700 r.p.m. motor, which is of lower first cost than the low-speed, direct-connected motor. But much of this advantage is lost on account of the cost of the chain, and in addition there is a maintenance expense with a chain; the chain is dangerous and must be guarded; and the motor on the table is in the way. Hence the use of direct-connected motors is considered the most satisfactory and,

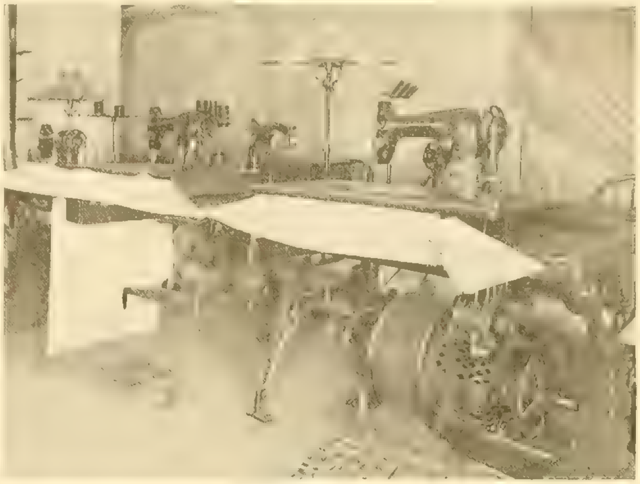


FIG. 3—SLOW-SPEED, DIRECT-CURRENT MOTOR MOUNTED UNDER POWER SEWING MACHINE TABLES
The cloth drops which normally surround the motor and shaft, are shown raised to allow a view of the apparatus.

in the long run, the most economical drive and it is therefore generally used.

Motors for direct connection can be coupled to the line shaft in three different ways:—

1—A motor with a single-extended shaft can be coupled to the end of the line shafting.

2—A motor with a double-extended shaft can be placed near the center of the table and coupled to two sections of the line shafting.

3—A motor with a double-extended shaft can be placed at the end of the table, with the pulley for the end sewing machine mounted on one shaft extension, while the other extension is coupled to the shafting for the rest of the machines.

The first method is the least expensive because an extra charge is made for a motor with a double-extended shaft. There is, however, a considerable dis-

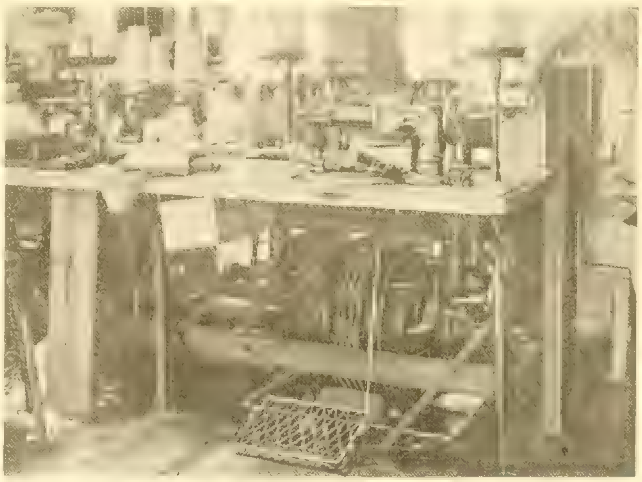


FIG. 4—3.5 HP, 450 R.P.M., SLOW-SPEED, ALTERNATING-CURRENT MOTOR MOUNTED UNDER POWER TABLE
Showing foot treadle control.

tance between the outer end of the motor and the first sewing machine and in consequence with this arrangement the motors stand in the cross aisles. Where space

is not at a premium, this is of no consequence, but ordinarily either the second or third arrangement is used because the motors then take up no valuable space. The third method is generally preferred because it places the motor at the cross aisle where it is more readily accessible than it would be if located near the center of the table.

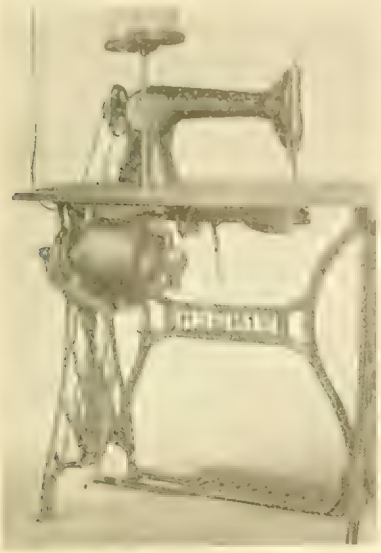


FIG. 5—DIRECT-CURRENT INDIVIDUALLY MOTOR-DRIVEN SEWING MACHINE

Both direct-current, shunt-wound motors and alternating-current, squirrel-cage motors are supplied for this drive. Their construction, except for the speed, is standard in every respect; their ratings range from one to five horse-power, and their speeds from 435 to 450 r.p.m. Starting rheostats are needed with direct-current motors, but knife switches ordinarily suffice for the alternating-current machines.

The power required for a given table depends upon the number of sewing machines, the type of the machines, the character of the material being handled and the operations being performed. In practice several of these factors are negligible and satisfactory operation can be obtained with motors selected according to the following table:—

Class of Work	Number of Sewing Machines per Horse-Power
Women's waists	16 to 18
Women's dresses	14 to 16
Women's cloaks and suits	12 to 15
Underwear	12 to 14
Men's shirts	7 to 9
Men's heavy garments	6 to 8
Bags and awnings	2 to 4

The most economical arrangement is to drive at least ten machines by each motor. If a given table is too long for the power of the available motors, the line shafting can be sawed in two and a motor used at each end. The motors should be set in drip pans and enclosed in wooden boxes with gauze sides, to keep out the debris that collects on the floor.

MOTORS FOR INDIVIDUAL SEWING MACHINES

For operating individual sewing machines a one-quarter horse-power motor is suitable for practically all types of sewing machines. This motor is mounted under the rear of the sewing machine table and drives the machine by means of belts and a friction clutch. The motor runs continuously but the machine is started and stopped and its speed is controlled by the pressure of the foot on the treadle. A snap switch is the only motor-starting device necessary.

OTHER ELECTRICAL APPARATUS

In addition to the sewing machine motors, garment factories use motors for driving box-making machinery, ventilating blowers, and the machinery in their small repair shops. The electrical cloth-cutter is also in general use. This machine is equipped with a one-quarter horse-power motor and has a capacity of about 1000 garments a day. Electric irons are needed in most garment factories and range from six pound irons for ladies light garments to the heaviest pressing irons for men's suits and over-coats.

Good illumination is essential for rapid and accurate work. Three lighting systems are in general use for the sewing machines;—*1*—a single 15 watt lamp over each machine; *2*—a 60-watt lamp serving four machines; and *3*—general illumination from 100 watt lamps suspended from the ceiling and furnishing a minimum of six foot candles intensity for white goods and eight for dark goods. General illumination from 60 to 100 watt lamps placed at eight foot centers is used for the cutting tables, offices and other departments.

The load factor for a garment factory varies between 24 and 50 percent with an average around 30 percent.

MOTORS FOR HOME WORKERS

The sweat-shop system, once the main source of ready-made garments, is still in existence, though gradually dying out. In this system, a contractor gives out jobs to the workers who do the work in their own homes. Until recently these people had to depend upon foot-power but now, wherever possible, they use domestic type sewing-machine motors, thus greatly decreasing their drudgery and increasing their earnings.

FIG. 6—INDIVIDUALLY MOTOR-DRIVEN FACTORY SEWING MACHINES
Used in the upholstery and top department of an automobile service station.

Experimental Investigation of Porcelain Mixes

G. I. Gilchrest and T. A. Klinefelter

PERHAPS the easiest way to state the problem of the ceramist in choosing the ingredients of a mix for electrical porcelain would be to imagine an ideal material possessing all desirable qualities to the highest degree,—a material which would pass rigid specifications and meet every actual requirement. Just what would be the result?

1—A material that would possess infinite dielectric strength, and insulation resistance.
2—A material of great toughness and resistance to shock, that would be undisturbed by stones thrown by the ever-present small boy, or by rifle balls.
3—A material having absolute resistance to temperature changes, no matter how extreme.

Of course, such an ideal material is not obtainable. The problem, therefore, is with the substances at hand, what can be derived in the way of high insulation, high mechanical strength and high resistance to temperature change? Can all these desirable qualities be obtained at 100 percent value in the same body mix? If they cannot, what is the limit and what should be sacrificed in one quality to attain a higher percentage in another? Having determined the foregoing, what materials in the mix are going to give maximum results?

Since porcelain forms the best all round insulation for electrical transmission lines, what is the best mix and materials for the porcelain primarily, and next, what is the best design to attain maximum electrical efficiency out of a given weight of material? The problem at the outset of this investigation was to determine the properties of mixes throughout the practical range of electrical porcelain. Obviously, the characteristics which were most thoroughly searched out were those considered most vital to the success of the product. However, some of the characteristics which have little effect upon the durability of the finished product were also compiled for use, if occasion should arise later and as a matter of general information.

Because of the inherent peculiarities of particular clays which are due to their molecular structure or at least to conditions not fully understood by ceramic engineers, the search for the best porcelain mix involves a large amount of experimentation as well as theoretical computation. In many manufacturing processes, it is possible to analyze the finished product and predict quite closely its trade value and characteristics. Also, it is often possible to take components as indicated by the analysis and duplicate the product. However, the analysis of a porcelain body only tells part of the story. In fact, the analysis may locate the porcelain mix so far as proportions of ingredients are concerned, but will not differentiate between clays, even between china and ball clays. That is, the effect of a particular clay upon the finished product depends upon characteristics of that clay, which cannot be determined by any known method of chemical analysis.

Throughout the investigation, the human element, that is so often apparent whenever several investigators pool their results, was eliminated to a large extent by having one investigator record all of the same characteristic. Obviously the comparative values of any characteristic should be fairly accurate.

TEST SAMPLES

The shape of the test sample is of vital importance. It should be of a design that is easy to manufacture, it should be of the general form of the usual finished commercial product and it should be convenient for test purposes. It was decided that a test cup shaped as in Fig. 1 would be most advantageous. The sides, bottom and radii were so proportioned that electrical punctures nearly always occurred through the bottom of cups and not through the edge or side.

SCOPE OF INVESTIGATION

In outlining the scope of this investigation, the triaxial diagram, Fig. 3 will locate the field covered. The diagram is self explanatory, indicating the relative areas of various commercial wares other than electrical porcelains. As evidenced, the field of investigation includes a range from low feldspar to high feldspar, no flint to high flint, low clay to high clay content. Moreover, it includes practically all commercial white ware bodies made; i. e., ordinary china, high grade china, porcelain of various sorts, etc. That is to say, the field is fairly covered so far as the three main ingredients, flint, feldspar and clay are concerned.

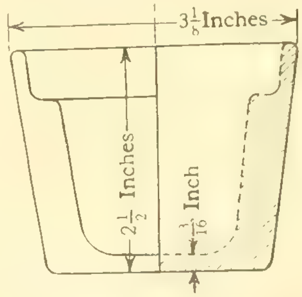


FIG. 1—TYPICAL PORCELAIN TEST CUP

The individual manufacturer of any particular line or kind of ware may add other ingredients in varying amounts, in order to obtain a desired color, translucency or strength, etc. In other words, he may specialize in one particular area of the field and endeavor to reach perfection at this point. After all, however, the main control is always by the three primary ingredients and the effect of their various combinations is really the subject of this investigation.

The body mixes were all made in a laboratory. They were blunged in ball mills, screened, filter pressed, pugged and jiggered in a manner corresponding as

nearly as possible with the procedure maintained in commercial production.

EASE OF WORKING

The ease with which the ingredients may be kept in suspension in water and thoroughly mixed decreases rapidly as the percentages of feldspar and flint increase, as shown in Fig. 4. This is especially true of the bodies very high in feldspar. The effect of the flint is less noticeable, unless the clay content is quite low. In either case, the feldspar and flint tend to settle out, if the slip is not kept in rather violent agitation. It would be exceedingly undesirable from the standpoint of mixing of the slip to adopt a body mix of low clay, high feldspar and flint content.

Moreover, the inherent properties of the particular clay cause considerable variation. Certain of the clays, due to their plastic nature and to the quantity of vegetable impurities, go into suspension more readily than others. They require a larger percentage of water to wash them through the screen in a reasonable time. In fact, in some cases, the percentage of vegetable matter is so great as to necessitate frequent cleaning of the shaking screen. Furthermore, if any appreciable percentage of a clay high in vegetable impurities is used, the resulting porcelain body will contain many small blebs caused by the burning out of the particles of vegetable matter during firing. Obviously, considerable data can be collected regarding this effect which explains the texture of the finished product.

The ease with which bodies filter-pressed and pugged varied in about the same manner as did the ease of mixing. It is essential that the body when taken from the pug mill should have a definite percentage of water; otherwise the material will not work properly when it is later formed into shape. In order to have the cakes of the proper consistency, the pressure must be increased as the clay content is decreased or the cakes will be soft. The feldspar and flint contents have the reverse effect each to about an equal extent. Also the time of pumping increased directly with the clay content, and again, the feldspar and flint content have a reverse effect. Substitution of a particular clay may of itself vary the time of pumping to a greater degree than would a material change of composition. The addition of a proportion of china clay at the expense of ball clay, tends to make the body more open and has the same effect as decreasing the total clay content.

Throughout the range of mixes, the bodies that worked easily in the processes of filter pressing and pugging, formed and jiggered into shape quite satisfactorily. An addition of china clay at the expense of ball clay has the same effect as an increase of flint at the expense of clay.

The rate of drying of the body samples followed logically the tendencies exhibited in the filter pressing. That is, mixes which pumped slowly, because of slow filtration of the water through the filter press cakes, also dried out slowly. The period required for drying increases very rapidly with the increase of clay content. An increase of the feldspar or flint content at the expense of clay decreased the period of drying, either of the former ingredients having about the same effect. Moreover, the addition of a proportion of china clay at the expense of ball clay increased the rate of drying quite appreciably.

Temperatures at which the test cups were fired were measured by means of pyrometric cones, a record of total time of firing, period of "soaking" at highest temperature, etc., being taken for each set of cups. Samples were fired from cone 7, 2318 degrees F. (1270 degrees C.), to cone *12*, 2498 degrees F. (1370 degrees C.), inclusive.. Of course, the dielectric strength, insulation resistance, resistance to impact blows, resistance to temperature changes and absorption ratio are the main qualities to be attained in electrical porcelain. However, these qualities being equal, the usual purchaser prefers a porcelain having the best general appearance as regards translucency, color, grain, etc.

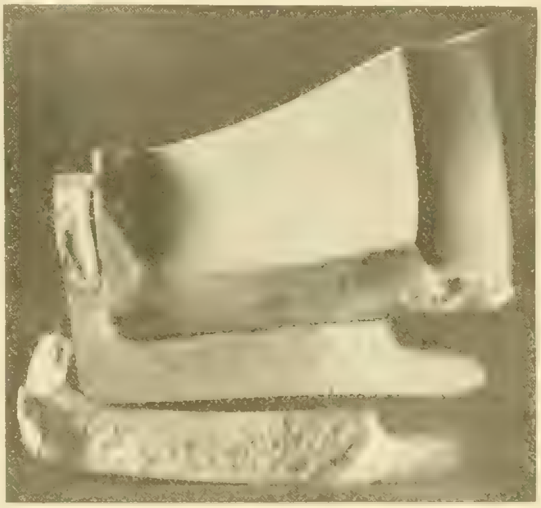


FIG. 2—FRACTURE OF BROKEN SECTIONS OF TEST CUPS FROM DIFFERENT MIXES

TRANSLUCENCY

The relative translucency of the bodies was judged by the degree to which ordinary daylight was transmitted through the bottom of the cups. Throughout the range of mixes, bodies having low clay and high feldspar contents were the most translucent, while all that were very low in feldspar were practically opaque as is shown in Fig. 5. In general, the translucency increases from two directions; namely, an increase of feldspar or decrease of clay, the kind of clay having a very marked effect. The latter is especially noticeable, if the proportion of china clay is varied, the translucency increasing rapidly therewith. Furthermore, the degree of vitrification often has more effect than a considerable change of ingredients, since some mixes that are opaque at cone *7* are decidedly translucent at cones *10* to *12*.

COLOR

Apparently the color (Fig. 6) of the porcelain body is practically a function of the clay content and

varies directly with its increase or decrease, the flint and feldspar contents having but a slight effect in comparison therewith. Also the body whitens quite rapidly with an increase of the proportion of china clay. Usually the temperature of firing has more effect than a considerable change of composition, the body lightening as the temperature of firing is increased. For example, consider a series of mixes containing a typical ball clay. At cone *10*, the bodies of 20 percent clay content will be quite white, while those of 30 percent clay content will have a decided yellow tint. At cone *8* the bodies of 20 percent clay content will appear about as yellow as those of 30 percent clay content did at cone *10*.

FRACTURE

The effect of range of mixes on the structure of broken sections is shown in Fig. 2. The top sample is high clay, high feldspar and no flint; the middle sample is medium clay, feldspar and flint, and the lower sample is low clay, low feldspar and high flint. The fractures

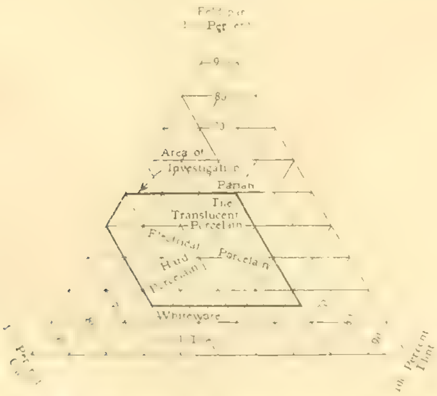


FIG. 3— TRIAXIAL OF AREAS OF COMMERCIAL WARES AND OF INVESTIGATION

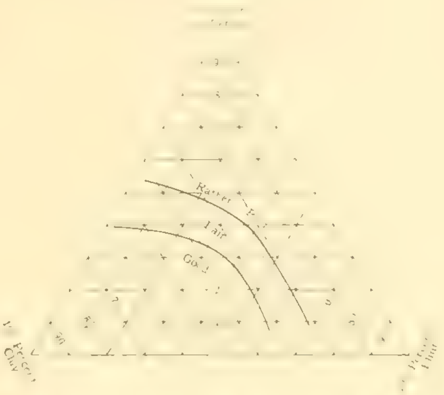


FIG. 4— TRIAXIAL OF RELATIVE EASE OF WORKING OF MIX

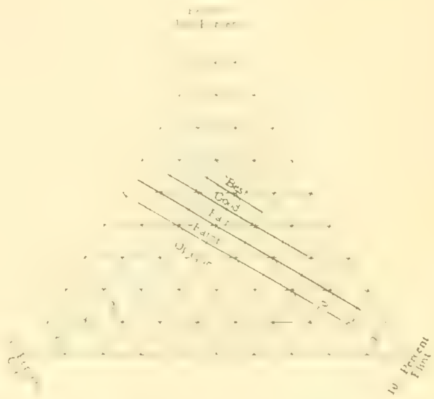


FIG. 5— TRIAXIAL OF VARIOUS DEGREES OF TRANSLUCENCY

of broken samples; that is, appearance and shape of edges appear to be a function of the flint content, the roughness increasing directly therewith as shown in Fig. 7. All bodies having a very smooth and conchoidal fracture are in the region of high clay and feldspar content and low flint content, the most conchoidal bodies containing no flint. An increase of the proportion of china clay makes the fracture less smooth and conchoidal while an increase of the temperature of firing works the reverse.

SPECIFIC GRAVITY

Evidently the specific gravity is a function depending largely upon the balance between fluxing and nonfluxing materials. Its value varies inversely with the flint content and directly with the feldspar and clay contents, the kind of clay influencing the results considerably. Increasing the proportion of china clay lowers the specific gravity while raising the temperature of firing increases it. Moreover, with low feldspar content and high proportion of china clay, the specific gravity may vary directly with the flint content, but this relation will exist only when the clay is mostly china. In the range of mixes investigated, the value varied from 2.46 to 2.08, the highest being for bodies of high feldspar, high clay (no china), and low flint, and the lowest for bodies of high clay (mostly china), low feldspar and high flint.

ABSORPTION

Relative absorption ratio measurements were taken on pieces of approximately 20 grams weight that were broken out of the test cups, care being taken to have the fractured surfaces fresh and clean. Samples were immersed in distilled water and final weight taken after boiling two hours and soaking one hundred hours. Primarily, the absorption ratio depends upon the proportions of fluxing material in the body and the degree of vitrification. Obviously the absorption ratio will increase with increase of flint content at the expense of either clay or feldspar, the latter being the main factor in giving a low value. Also the absorption ratio will increase rapidly with the increase of proportion of china clay, while an increase of firing temperature produces the reverse effect.

SHRINKAGE

Considered from the standpoint of the commercial product, shrinkage of the body during drying and firing is of no consequence. Nevertheless, it is of utmost importance in factory production, wherever the dimensions must be within specified limits. In general, it appears that if the clay content is mostly ball, the shrinkage is practically a function of the flint and clay contents, varying directly with the clay and indirectly with the flint. When a considerable proportion of china clay is used the feldspar also exerts a material influence toward increasing the shrinkage. Bodies of highest shrinkage all occur in region of high clay, low flint and bodies of lowest shrinkage in region of low clay and high flint. The shrinkages in the area covered varied from 5.5 to 27.5 percent.

DIELECTRIC STRENGTH

In arriving at the relative dielectric strength, (Fig. 8,) puncture tests were made with the cups between mercury electrodes; that is, the test cup was set in a

three-sixteenth inch bath of mercury and the inside bottom covered. Samples were tested under oil, being set in the mercury bath and mercury poured into the cup before immersion, so as to prevent the formation of an oil film. Sixty cycle voltage was supplied at the rate of three or four kilovolts per second until breakdown, a series of tests being carried out at usual air temperature and at 170 degrees F.

In the region of high feldspar content, the dielectric strength is mostly a function of the feldspar content and varies directly therewith, while in a low feldspar region its value also varies directly and quite rapidly with the clay content. The dielectric strength varies inversely with increase of flint or proportion of china clay. Furthermore the dielectric strength, especially of low feldspar bodies, increases rapidly with the increase of temperature of firing. The bodies of highest value occur in the region of high feldspar, low flint, and those of lowest value in the region of low feldspar, high flint. The range of dielectric strength was from 5000 volts per 100 mils to 39 000 volts per 100 mils. Apparently the average dielectric value of the bodies that would be practical for electrical porcelain was decreased about six to ten percent by the increase of temperature during test from 79 degrees F. (26 degrees C.) to 170 degrees F. (77 degrees C.).

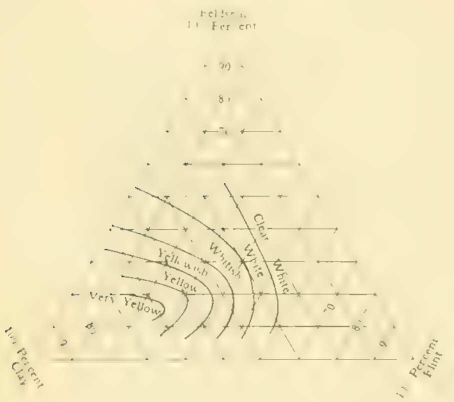


FIG. 6—TRIAXIAL OF VARIATION OF COLOR

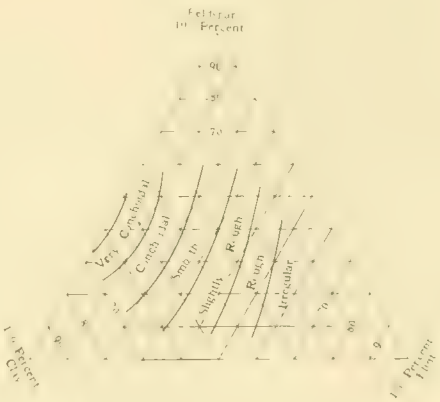


FIG. 7—TRIAXIAL OF FRACTURE OF BROKEN SECTIONS

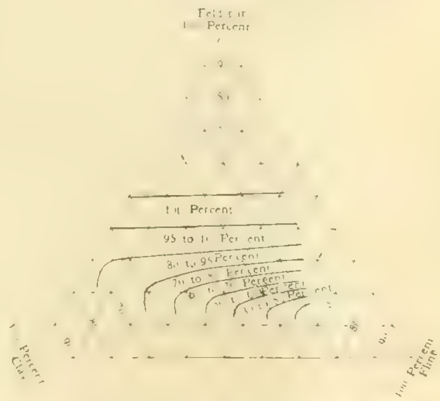


FIG. 8—TRIAXIAL OF RELATIVE DIELECTRIC STRENGTH

Insulation resistance measurements of the bottom of the cups were taken, using mercury terminals as in the case of dielectric strength. The tests were obtained by means of high-voltage direct current, galvanometer readings being recorded after one minute's electrification at 5000 volts. In general the results checked very closely with the 60 cycle puncture tests. However, cups having a laminated or blebbed structure were not differentiated from those of better manufacture. Moreover the temperature of firing affected the insulation resistance to a much less degree.

RESISTANCE TO MECHANICAL BLOWS

Sufficient difference of resistance to impact blow, Fig. 9, existed in the series that a fair idea of the variation could be obtained by breaking one or two cups of each mix with a small hammer. However, in order to obtain data less dependent upon the human element, a small testing machine was constructed. The test cup was placed in a V-shaped groove which was slanted so that the upper side of the test cup was horizontal. A one-half inch diameter plunger having spherical ends was held vertically by bearings and rested against the middle of the horizontal side of the cup. A one pound weight running in guides was arranged to drop on to the plunger from various heights. In testing a sample the weight was raised to a six inch height and let fall, and a two inch increment was then added to each succeeding drop until the cup shattered. All samples were put through the same cycle of blows up to failure and the height of drop at failure was taken as the bodies' comparative resistance to impact blow.

The resistance to impact is mainly a function of the flint content and varies directly therewith. An increase of flint at the expense of either feldspar or clay increases the mechanical strength rapidly, although the effect of the clay is by far the most decided. Increasing the proportion of china clay decreases the strength, but this is of minor consideration compared to the effect of the flint content. An increase of the burning temperature decreases the mechanical strength materially, especially if the body is of a high feldspar content. In fact the temperature of burning often made a difference of 30 percent in the samples of the same body mix. Bodies of greatest resistance to impact lie in the region of high flint, low clay and medium feldspar contents while the bodies of lowest resistance lie in the region of low flint, high clay and high feldspar contents, the lowest of all containing no flint. The comparative relations between the highest and lowest bodies were approximately four to one.

RESISTANCE TO LOCAL HEAT

Three methods were tried for obtaining the comparative resistance to local heat application, shown in Fig. 10. In the first place a series of cups was put through a considerable number of cycles by transferring them between water baths consisting of boiling water and ice water, but the method was not severe enough to give comparative results. A second series of

cups was then heated in an air oven to 536 degrees F. (280 degrees C.) and plunged into water. Definite results were obtained but the test did not seem convenient in consideration of the wide range of body mixes. The method finally selected consisted of a blow torch and framework, so arranged that the test cup would always be placed in the same position relative to the blow torch nozzle. In testing, the cup was set so that the edge split the blow torch flame at a distance of two inches from the nozzle, care being taken to keep the length of the flame constant. Time was taken from instant of setting the cup into the flame until the first explosion or crack occurred.

Resistance to local heat application is most dependent upon the flint and clay contents, the flint being somewhat more effective. The resistance varies directly with the clay content and indirectly with the flint content. The feldspar content has less effect but high feldspar means rather low resistance. An increase of proportion of china clay tends to lower the resistance of the body while an increase of the temperature of firing increases it. Both the latter elements are slight here as compared to their effect upon other body properties. The bodies most resistant to local heat application lie in the region of high clay, low flint, while those of least resistance lie in the region of low clay and high flint. The comparative relations between the highest and lowest bodies were approximately 5 to 1.

The above results having been worked out by using a single ball clay and a single china clay, the next step was to try various clays of both sorts in a number of the bodies, no longer bothering with extremes. This was for the purpose of determining how the individual characteristics of a clay would affect the areas already worked out. It was found that considerable variation did exist, but in general each clay showed the same general tendencies, the areas shifting somewhat in each case.

Taking advantage of these "shifts", combinations of clays were next made up in several of the best body mixes, in an attempt to combine all the good points and eliminate the weaker, or in other words, to try to combine the three main properties at 100 percent as nearly as possible, or in as small an area as possible. With the materials used, and at the kiln fire to which they were subject, no one mix of this sort was found. Nor was the area obtained by drawing lines from the three 100 percent points as small as desirable.

CONCLUSION

In summing up, the three main properties are given the most consideration; that is, dielectric strength, mechanical strength and resistance to sudden temperature change. For purposes of comparison a final triaxial was plotted, Fig. 11, showing in a general way the areas where these three properties seem to be located by the investigation in the highest degree. High dielectric strength appears to be characteristic of a high feldspar content; high mechanical strength of a high flint content; and high resistance to local heating of a high clay content. It would appear that all three properties in the very highest degree are not likely to be found in any one body. That they can be obtained in a very good working percentage for each one was clearly shown throughout the whole investigation in those bodies lying inside the area bounded by the lines drawn from the maximum points. Furthermore, each property can be helped or raised in a body by the use of certain clays or certain mixtures of clays or by variation of the kiln fire. Sometimes this occurs somewhat at the expense of another property if care is not exercised.

At the temperature fired and with the materials in use, one cannot expect to obtain the maximum dielectric strength, maximum toughness and maximum resistance to temperature change, all in one body. But a maximum of any one property can be obtained and a fair or good working percentage of one or both of the others, or a very fair medium of all three properties. This latter is doubtless the more logical if due consideration is given to the commercial application of the finished product.

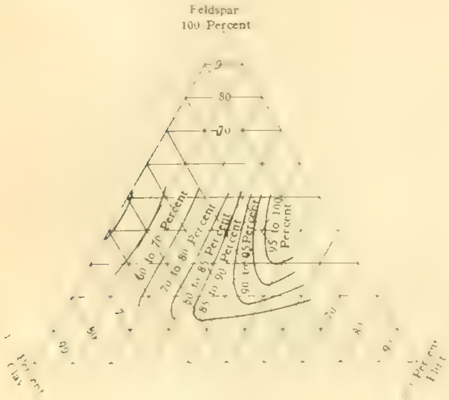


FIG. 9—TRIAXIAL SHOWING RESISTANCE TO MECHANICAL BLOWS

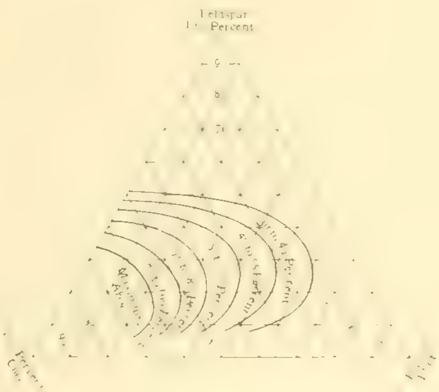


FIG. 10—TRIAXIAL SHOWING RESISTANCE TO APPLICATION OF LOCAL HEATING

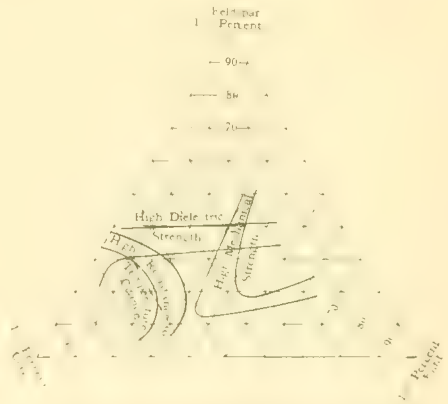


FIG. 11—TRIAXIAL SHOWING AREAS OF MAXIMUM VALUE

The Engineering Evolution of Power Plant Apparatus—XXVI

A Historical Review of Steam Turbine Progress

Francis Hodgkinson

ALONG with the improvements in turbine performances already discussed have been corresponding improvements in details which have materially increased the reliability of steam turbines. Some of these details, for example, the blading and governing systems, have in themselves gone through a process of development which will be reviewed briefly.

BLADING

There has been a good deal of misapprehension concerning turbine blading. With all types of turbines, the design and material of turbine blading have undergone some evolution. Of necessity, blading is subjected to very arduous conditions. It works in a steam current of considerable velocity, the steam often being laden with moisture and sometimes with chemicals and solid foreign particles as the result of priming boilers. Centrifugal stresses must of course be properly considered, but far more important is the fact that any blading must be able to withstand the tendency to vibrate in the steam current.

The characters of the two salient types of turbine elements, impulse and reaction, require quite different blading; the one, massive blade sections, and the other, relatively light sections. However, the strain on the blades due to centrifugal force is the same in either case, and in the event of collision between blades the one is as subject to injury as the other, with the difference, however, that the results may be more far-reaching in the case of the more massive blades. In some of the early designs, breakages were due to contact between the stationary and revolving elements, resulting from distortion of the cylinder structures. This has been eliminated by better design of these structures, the elimination of ribs and all unnecessary excrescences which might lead to internal strains in the castings or distortions due to uneven heating and cooling.

The principal cause of breakage of turbine blades is vibration in the steam current. There are scarcely any records of blades having broken because of centrifugal force *per se*. Shrouding and other means of bracing the outer ends of turbine blades to each other have been employed to reduce the tendency to vibrate. Such devices increase the natural periodicity, and hence reduce the amplitude of vibration. Later designs of blading have their sections tapered, there being some 40 percent more cross-section at the foot than at the tip. With this construction, the deflection due to vibration will be distributed over a considerable length instead of being concentrated at the point of attachment. The later method of attaching reaction blades is shown in Fig. 26, the blades having a foot forged on the end which fits in a groove in the floor of the main groove of the blade-carrying element. The spacers between the blades are dovetailed to correspond with the dovetailing of the main groove, thus completely interlocking the blading and rendering the attachment as strong as the blades themselves. Large blades, like those shown, have their grooves provided with compound wedges which help to fill the grooves more completely. This type of blading was first employed in all commercial turbines in 1911, since which time little trouble has been experienced due to vibration of blades. This construction replaced the reaction blade system devised by Parsons in 1896 which comprised alternate blade and spacing pieces, each drawn to shape and cut to length and calked in grooves very slightly dovetailed; the root portion of the blades being slightly serrated, but friction, the result of calking, was wholly depended upon for securing the blades.

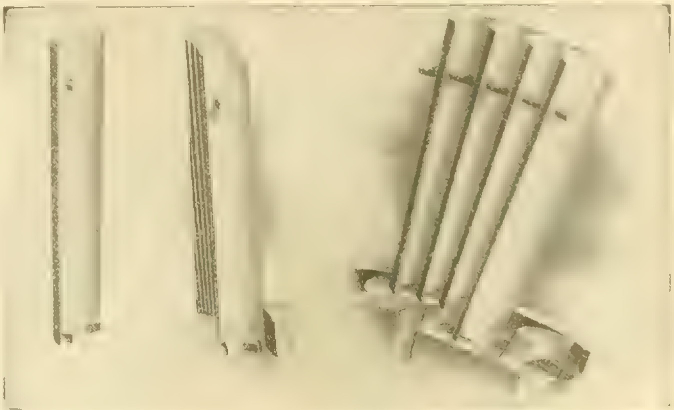


FIG. 26 METHOD OF ATTACHING MODERN REACTION BLADES
Showing also comma wire blade lashing

Ingenuity on the part of builders of reaction turbines has not been lacking in suggesting improvements, but the apparently crude construction of Parsons was not easily to be improved upon, for it is still employed by builders of reaction turbines in Europe. The Fullager system was introduced in 1904, and was employed by the Allis-Chalmers Company in the United States and by William & Robinson in England. The Allis-Chalmers Company were compelled to abandon the riveted shroud portion of the Fullager system on account of a patent covering this, controlled by the General Electric Company. They have since made further improvements to their construction.

BLADE LASHINGS

In the earlier machines, the blades were short and steam velocities low, so no blade lashings were required.

Earliest blade lashings comprised a metal strip laid in a notch in the side of the blade, laced to the blades with fine wire and silver soldered. This method is still employed in Europe, except the lacing is discontinued and silver soldering relied upon entirely. The Westinghouse Company early abandoned this method and adopted in 1905 what is known as a "comma" wire construction, shown in Fig. 27; the tail of the comma being sheared at the walls of the blade and turned over between the blades, thus forming an abutment against the blades. This construction, while simple, was found after some years of use to be objectionable because of the close inspection required to insure a solid abutment, without which the blade may commence vibrating slightly between the abutments, the vibration increasing its amplitude on account of wear, until rupture is reached.

In the last few years silver soldering of the comma wire has been employed as an insurance and to avoid difficult inspection, the construction otherwise remaining the same. The clinching of the comma wire serves as a ready means of spacing the ends of the blades

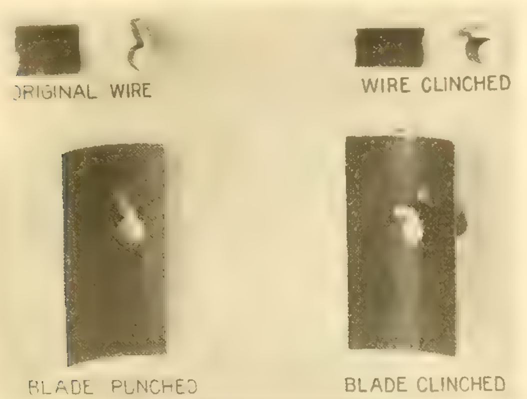


FIG. 27—COMMA WIRE METHOD OF CLINCHING BLADES

properly, after which the soldering may be performed. Brazing spelter was for a time employed in order to avoid the high cost of silver. It was found objectionable because the higher heat involved necessitated the blade cooling under some shrinkage stresses, through what appeared to be a critical temperature, sometimes causing rupture.

With later designs, involving large steam volumes at high velocities, the blade lashing is of paramount importance in order to reduce vibration in the steam current, and judgment must be employed in determining the length of segments to obtain the maximum rigidity on the one hand and to provide the necessary flexibility for expansion on the other; it being remembered that the blading heats and cools at a different rate from the supporting drum or disc.

IMPLUSE BLADING

As previously stated, impluse blades partake of a construction different from reaction blading. Generally they are more massive and the fourth wall to the blade passage, formed by a shroud, is always employed. Impulse elements were not employed commercially by the Westinghouse Company until the advent of their single-double-flow combination turbine in 1909. A number of different forms of impulse blade constructions have been employed, not all of which are instructive. A modern standard construction of blading for two-row impulse elements is shown in Fig. 28. Two constructions of a single row impulse element (Rateau turbine)

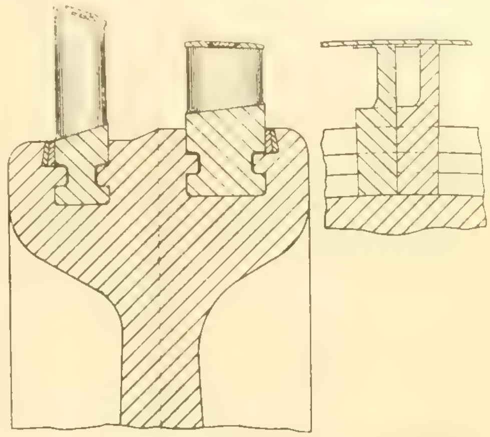


FIG. 28—TWO-ROW IMPULSE BLADING ELEMENT

are shown in Fig. 29. In each case, the shroud is integral with the blade. A groove is cut in the shroud into which is inserted a strip of suitable length, which is brazed to the blade. The blade is drawn to the shape corresponding to the shrouded portion, the blade portion between the shroud and base parts being formed by a profiling milling operation.

BLADE MATERIALS

A brass alloy, known as Delta metal, was employed for reaction blades for the earliest machines in this country. Some blade breakages, which no doubt were due to vibration of the blades themselves, were attributed to defects of the material; such as crystallization, due to heating and cooling. Careful trial in a few machines showed us that blading made of ordinary

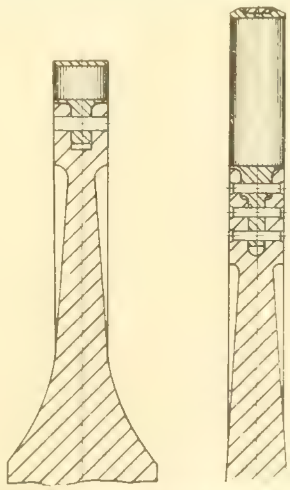


FIG. 29—STANDARD SINGLE-ROW IMPULSE ELEMENT

steel would not corrode, so between 1904 and 1907, steel was adopted, and many of these machines are in operation today without showing any particular corrosion. However, enough cases of severe corrosion appeared to render the use of ordinary steel blading untenable.

The effects were obviously caused by corrosion (not to be confused with erosion) and occurred mostly at the dew point, that is, at the zone of the turbine where, on account of latent heat being given up, superheat is lost and moisture commences to be precipitated. The cause of corrosion in power house apparatus seems obscure; it exists in one plant, and is absent in another, and the analytical chemist has not been of material assistance in determining specific causes. No doubt injudicious use of boiler compounds and the presence of unsatisfied oxygen with pure water were among the reasons.

In 1907 blades were made from Monnot metal, the original steel ingot having 25 percent of copper welded to the outside by a proprietary process, subsequent rolling and drawing still maintaining the proportion of copper in the final blade shape. While more resistant to corrosion, they were by no means immune. So a bronze alloy was again adopted; this time using an alloy containing copper 97 to 98 percent, tin 2 to 3 percent, phosphor 0.03 to 0.07 percent, which, for moderate stresses is still employed. For higher stresses and impulse blading a low carbon steel is employed having a carbon content not to exceed 0.08 percent, combined with five percent nickel. This is practically a nickel iron, manufactured in an electric furnace.

The quality of material has always been considered as being a considerable factor in the ability of a blade to resist fracture under vibrating stresses. No doubt homogeneity is important, and some low carbon steel made by ordinary processes has failed for lack of it. It would appear that while the strength of a section under tension depends upon the average strength of the fibers, the ability to resist vibration is perhaps only dependent upon the strength of the weakest fiber.

A variety of materials have been suggested for blading, and employed at one time or other by various manufacturers; a few may be commented upon as follows:—

Nickel-Steel, higher in both nickel and carbon than that mentioned above, is used in Europe, but alleged to be by no means immune from corrosion.

Nickel Bronze (80-20) has been successfully employed by some manufacturers. It is alleged to become brittle by absorbing carbon monoxide should it be present in the steam.

Monel Metal has satisfactory characteristics but is difficult to work and varies in composition.

Nickel, if pure, has satisfactory physical characteristics and is immune from corrosion.

GLANDS

In their early turbine work, the Westinghouse Company employed a steam labyrinth similar to that employed by Parsons. It had the objection that to provide enough sealing steam to preclude air leakage invariably meant an objectionable leakage to the engine room. In 1903 was developed the well known water gland which has been employed without material change until this time. It comprises simply a double centrifugal pump operating in a chamber. It is provided at its periphery with water, say of five pounds greater pressure than the pressure against which it is designed to pack, the pump being designed for a pressure ten pounds higher than this, should it be full of water. The pump thus maintains an annulus of water at the outer edge which forms a very complete seal.

The advent of water glands reduced a troublesome and difficult detail to one causing no concern to either the designer or manufacturer. It is extremely simple

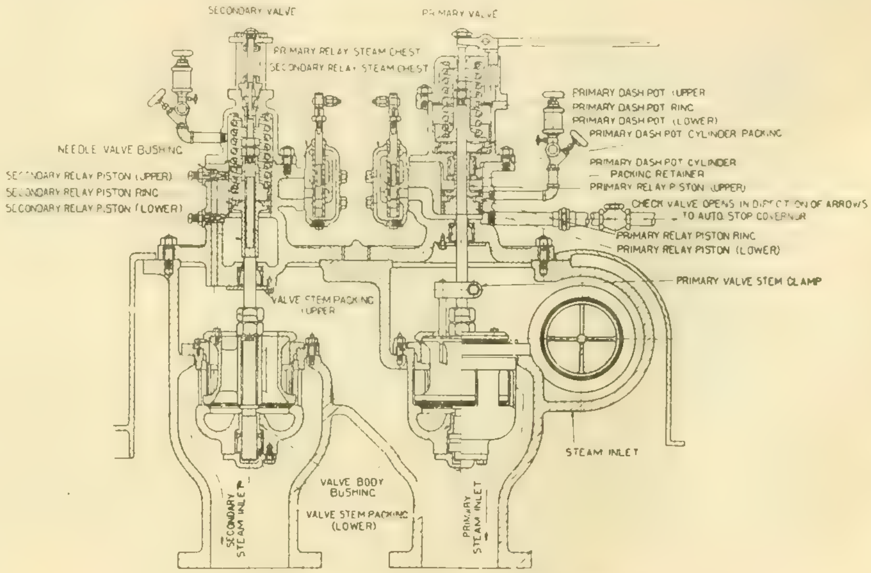


FIG. 30—SECTION OF VALVE CHAMBER OF A STEAM TURBINE
Showing steam relay type of valve gear.

in operation, requiring only a supply of water of the requisite pressure. This is best supplied by a float valve and tank located at the proper elevation. Inasmuch as there is some evaporation taking place in the gland, in part due to transfer of heat along the cylinder wall and to fluid friction of the fluid itself, water containing scale forming matter should not be used, so the gland is preferably supplied with condensate.

This type of gland has been extended to use with marine propelling machinery, in which case the gland must pack at any rotational speed in either direction so a labyrinth packing is provided in combination with the water seal. Further the turbine governor is arranged to turn off the water supply and admit steam through a reducing valve to the labyrinth automatically, whenever the speed of the turbine is reduced below that at which the water gland can seal, usually about half speed. This is accomplished by providing the governor with two springs, one heavier than the other. The first half of

the governor travel compresses the lighter spring at only about half full speed. The governor on reaching this position, operates a relay, turning steam on and water off, or vice-versa, according to whether the turbine is being accelerated or retarded. On the turbine reaching full speed, the governor will go to the outer half of its travel, compressing the heavier spring and controlling the main steam admission.

BEARINGS

The bearings devised by Parsons in 1890, comprising a shell surrounded by three concentric sleeves, are still employed for turbines that operate above their critical speed. Such turbines, however, are few in number for, so far as practicable, all modern machines operate below their critical speeds. For these, ordinary cast-iron bearing shells are employed, lined with babbit. The progress represented in them is that pressures per square inch of projected area have gone from 50 to 120 pounds and surface speeds from 50 to 80 or 90 feet per second, and it is believed that the duty to which such a bearing can be subjected is considerably beyond these limits.

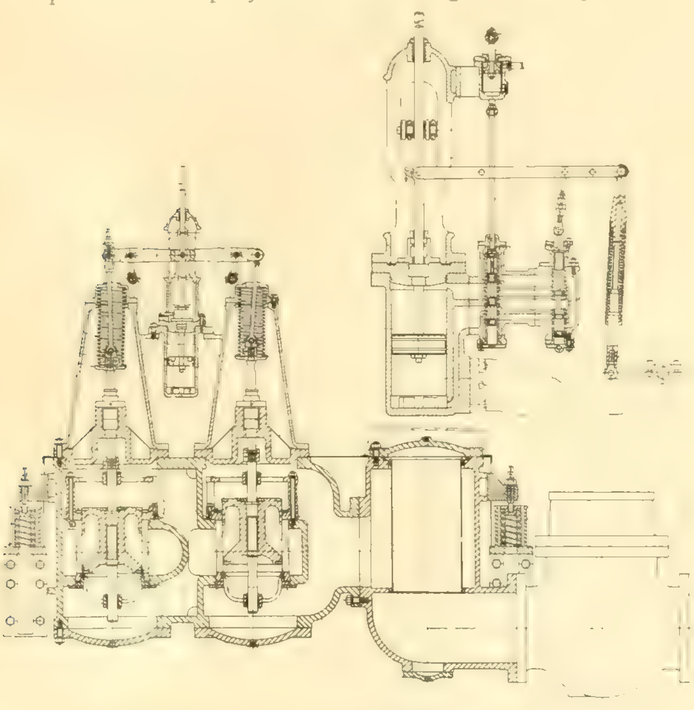


FIG. 31—TYPICAL CONTROL VALVE WITH RELAY
For a large steam turbine.

An innovation, introduced by the Westinghouse Company at the inception of their turbine work, was to provide the turbine bearing shells with four keys fitted in recesses on the outside. These keys have sheet metal liners beneath them, and are turned spherically to suit the housing which supports the bearing, the bearing being supported by the keys in the pedestal. Removal of liners from one side to the other provides a very definite adjustment of the rotor in the turbine cylinder. By these means the position of the rotor may be easily determined as well as definite knowledge of the least radial clearance obtained. The rotor may be displaced definite amounts, and the rotor meantime revolved, permitting an adjustment of position to be made that beyond peradventure is what is required.

THRUST BEARING

The thrust bearing, comprising a number of collars, has been replaced by the Kingsbury thrust bearing which is capable of supporting an enormous thrust, enabling turbines to be constructed to have a considerable normal end thrust, and permitting the reduction of diameters of balancing pistons and the like. Furthermore, with such bearings an accurate balancing of the turbine, so that there shall be no end thrust, is no longer necessary. These thrust bearings operate satisfactorily with pressures as high as 500 pounds per square inch of actual bearing surface. They have been operated experimentally with pressures as high as 5000 pounds per square inch without heating. Dr. Kingsbury has secured a variety of applications for his bearing wherever a high-duty thrust bearing is required, including heavy vertical generators. Most modern geared turbine steamers are being equipped with them for the main propeller thrust bearing; the multicollar type of marine thrust bearing, seven or eight feet long, being replaced by a single disc occuping an axial dimension of less than two feet.*

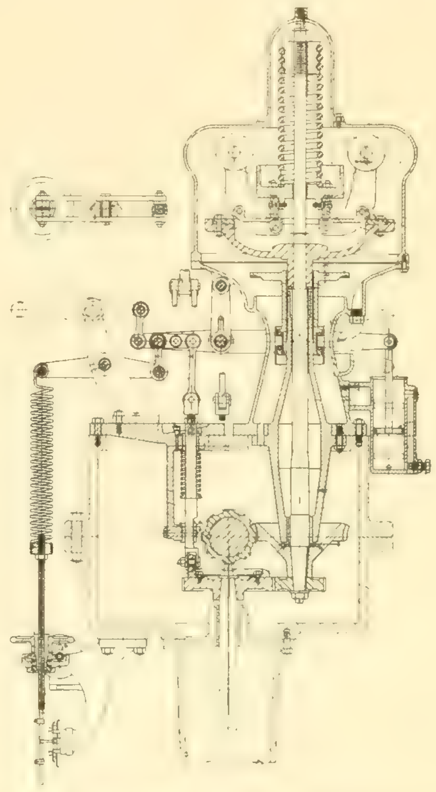


FIG. 32—GOVERNOR FOR VALVE OF FIG. 31

GOVERNORS AND GOVERNOR VALVES

A speed-responsive centrifugal type of governor has always been employed in this country. A development of detail design has occurred which is of considerable interest, but would be of too great a length to be

*These bearings are described in detail in an article on "The Kingsbury Thrust Bearing" by Mr. H. A. S. Howarth, in the JOURNAL for Aug. '15, p. 351.

described here. The result is the employment today of governors of large power and of such construction as to assure a perfectly constant rate of speed variation.

At the time the Westinghouse Company became a licensee of Parsons, it was Parsons' custom to control all machines by an electrical governor, comprising a solenoid actuating a steam relay. The solenoids were compounded and could be arranged to maintain substantially constant voltage, in which case the turbine operated at higher speed at full load than at friction load in accordance with the generator characteristics. Parsons was able to obtain excellent regulation from a solenoid, by introducing a constant oscillation to the lever system that connected the relay with the armature of the solenoid, effectively eliminating friction of rest. This also oscillated the relay, causing a quite violent opening and closing of the main valve and admitting the steam to the turbine in puffs. At that time there were few cases in Europe where alternating-current generators operated in parallel, so the electrical governor was satisfactory.

The governor control employed by the Westinghouse Company in their earliest machines employed a similar steam relay, substituting a speed responsive flyball governor for the Parsons solenoid. The steam relay went through a process of elaboration and improvement. Arrangements were developed for the automatic operation of by-pass valves by the same system to enable the turbine to carry heavy overloads. An example of this valve gear is shown in Fig. 30.

The character and the quickness of governing to be obtained with such a mechanism left nothing to be desired. An objection to it was that its method of operation was not obvious to the observer, and the cause of any little derangement was not easily diagnosed. Later with the advent of larger machines, the puff system of admitting steam was found to cause at times objectionable reaction and vibration in the main steam lines of the power house, so that by 1909 the steam relay began to be abandoned for the well-known hydraulic relay and floating lever that is employed today, using oil at 50 pounds pressure provided by the regular turbine oiling system. At this time it was arranged that in cases of smaller turbines, where the steam flow was 20 000 pounds or less per hour, no steam relay would be employed, the regular governor being sufficiently powerful to operate the valves direct.

Control Valves—In the earlier machines, cast-iron or ordinary bronze, double-beat, poppet valves were thought good enough. The higher superheats and larger capacities of today have brought about considerable changes in these parts. A high grade nickel bronze is employed for quite small sizes. Generally, steel is employed for all parts, the seats in both the valve and cage being formed by monel metal rings suitably secured in place, the life of which appears indefinite. A modern control valve with its relay for a large turbine is shown in Fig. 31, and the design of the governor controlling it, in Fig. 32.

Automatic Stop Governors—All machines except the earliest have been provided with automatic stops. There has been no particular change in these during the last ten years. In earlier machines, it was thought preferable that the automatic stop governor should operate a separate and distinct valve in the main steam line. This was found objectionable in some cases as the separate automatic valve would never be operated except in the emergency when, on account of long disuse, it may be found to be inoperative. It was therefore abandoned and the main throttle valve itself arranged to be operated automatically by the stop governor. The advantage of such an arrangement is;—first, the valve must necessarily be maintained tight; second, of necessity it must be operated every time the turbine is started or stopped; and third, the valve may be partially closed even while the turbine is operating, so there may be assurance of no sticking in the pistons, etc. Fig. 33 represents a modern throttle valve of this type. The seats are of Monel metal which appears to be the metal most capable of resisting the erosive action of steam.

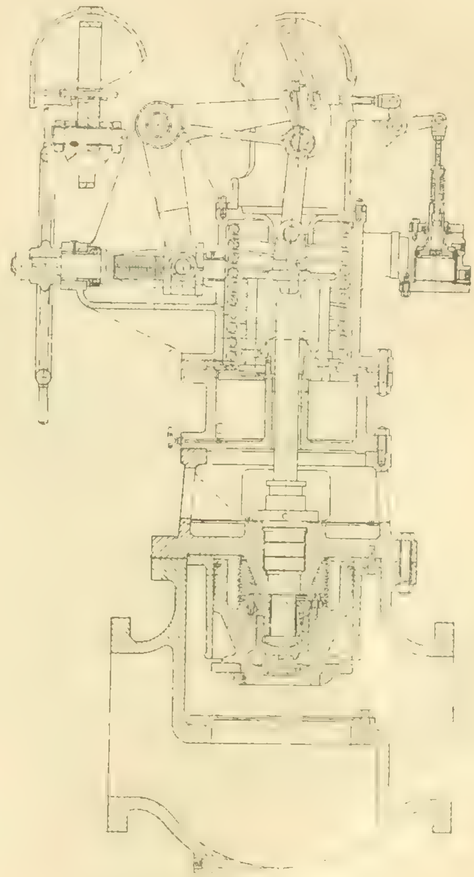


FIG. 33—MODERN AUTOMATIC THROTTLE VALVE

(To be continued.)

Industrial Controllers-XV

Machine Tool Controllers (Cont.)

H. D. JAMES and A. L. HARVEY

In the February issue were described the individual units from which complete machine tool controllers can be made. In this issue various applications are described.

ONE of the most significant movements of the past year or two has been the effort to guard employees from physical injury. The principal danger from electrical apparatus is a shock or burn, due to contact with live parts. Control apparatus should be so guarded that the operator will not come in contact with live parts when handling any of the control apparatus necessary for his work. It should also be protected so that tools, pieces of iron, chips, or other material cannot come into accidental contact with live parts. This may be accomplished by enclosing all current carrying parts and providing projecting handles for the operation of the switches; or the control panel may be protected by grill work; or placed eight feet above the floor. The master controller should be arranged in a convenient manner so that the operator is not required to reach across his machine or in any way expose himself to injury during the operation of his machine. This convenience also increases production.

FIG. 1—UNIVERSAL WOOD MILLING MACHINE
Driven by a reversible direct-current motor with speed adjustment by field control.

In some cases, it is desirable to provide several stations, from which a machine can be stopped in case of accident. These stations usually consist of push buttons wired in series with the operating coil of the contactor or a low-voltage coil, so arranged that the pushing of any button opens the circuit and disconnects the motor from the line. A universal wood-milling machine which is motor-driven and provided with three control elements is shown in Fig. 1. At the base of the pedestal is mounted a cabinet containing the line switch and fuses together with a line and an accelerating contactor. On the inside of the cover which can be locked in the closed position is attached the wiring diagram and instructions. The knife switch is operated by a handle extending through the right-hand side of the cabinet. This knife switch is used only for disconnecting purposes and can be locked in the open position. Near the center of the table and located on either side of the operating levers of the machine is located a field rheostat and a drum reversing switch. Both of these are covered to prevent contact with live parts.

A radial drill is shown in Fig. 2. The same cabinet is used as in Fig. 1. The motor is non-reversing and the master switch is combined with the field rheostat. Fig. 4 illustrates a coil winding table. A number of these tables are located together and in the background can be seen the control cabinets for six tables. There is a handle on the outside of the box for opening the knife switch. A contactor with a blowout is in series with the motor; two other contactors short-circuit the starting resistor during acceleration. Each table is provided with a reversing drum controller and a field rheostat. The drum controller also serves as a master switch and is operated by a treadle. The push button, shown underneath the reverse switch in Fig. 4, is a reset button for low-voltage protection. In case of failure of voltage, the motor cannot be started again without pushing this button.

A turret lathe with an older form of control panel, in which the field rheostat is mounted on the panel with the contactors is shown in Fig. 3. While many of these panels are still in use, they may not comply with many safety requirements now enforced, as

FIG. 2—ELECTRICALLY OPERATED RADIAL DRILL
Driven by non-reversing shunt motor with speed adjustment by field control.

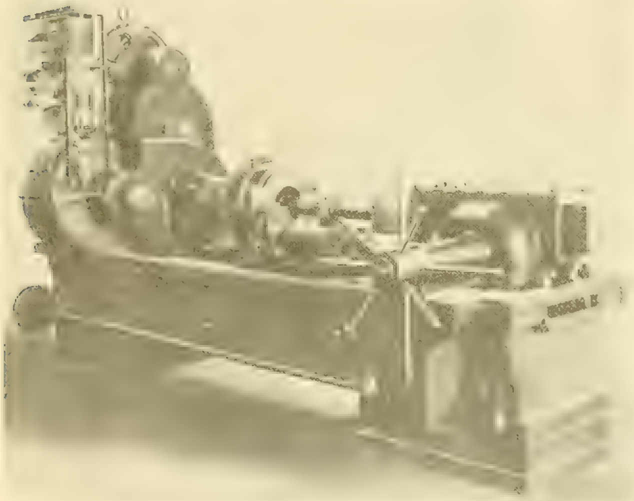


FIG. 3—ELECTRICALLY-OPERATED TURRET LATHE
Equipped with old style control panel which has the field rheostat mounted with the contactors.

FIG. 4—SMALL COIL WINDING TABLE
Operated by a reversing direct-current motor, with speed adjustment by field control and low-voltage protection with reset button.

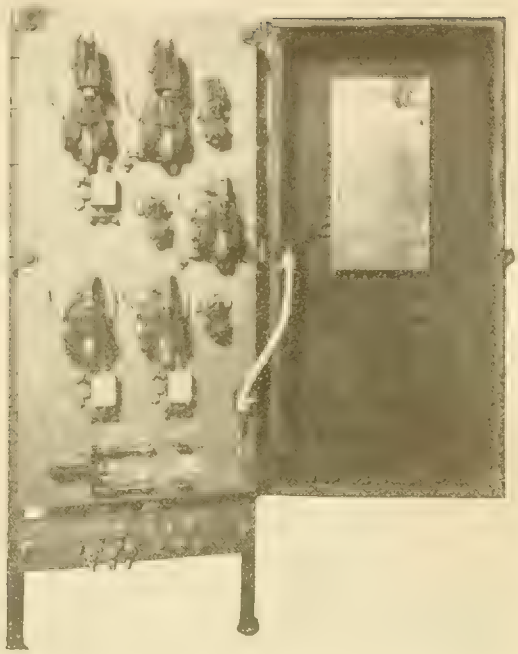


FIG. 5 WHEEL-LATHE CONTROLLER
When this panel is equipped with a cover, the field rheostat is mounted on the inside and operated from a handle on the outside.

FIG. 6—TURRET LATHE WITH DRUM CONTROLLER
For reversing service. A field rheostat in the bottom of the controller is used to adjust the speed of the motor.

FIG. 7—MOTOR-DRIVEN ENGINE LATHE
The controller is operated from the spline shaft of the lathe.

the operator can readily obtain a shock by carelessly placing his hands on a live part of the control.

Fig. 6 represents the use of a drum controller arranged for armature starting and speed regulation by field control on a turret lathe. The controller is located close to the motor on the head of the machine, making a compact installation. The operator manipulating the machine stands within easy reach of this controller. This same form of controller is shown in Fig. 7 operated from the spline shaft

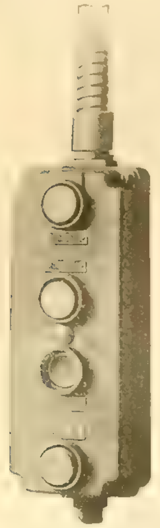


FIG. 8—PUSH BUTTON PENDANT SWITCH

FIG. 9—PLANER MASTER SWITCH

of the lathe. This same arrangement can be used with the drum reversing switch and a separate control panel.

The methods of control illustrated in Figs. 1 to 7 are very simple, consisting of a line switch which may or may not reverse the motor, together with suitable means for short circuiting the starting resistance. A field rheostat may be added where adjustable speed motors are used. Applications of this kind do not present

FIG. 10—REVERSING PLANER CONTROLLER

Operating a 4:1 speed direct-current motor. The handles for the field rheostats are shown in the cover of the controller to the right of the motor. One handle is used for adjusting the speed of the cutting stroke and the other for the return stroke. On the side of the planer is shown the master switch connected to the reversing gear operated by the platen of the planer. In front of the planer head is shown the pendant switch. Close to the main motor is a small drum reversing switch for controlling the motor which operates the tool carriage.

any unusual control features. While they can readily be made up from the units described in the JOURNAL for February '18, p. 63, the arrangement must be made to suit the particular design of machine. Some other applications, however, require considerably more study.

WHEEL LATHE

The application to the wheel lathe requires special consideration in order to obtain the maximum convenience in the operation of a machine designed for this particular purpose. The controller is illustrated in Fig. 5 and is operated by a push-button station having buttons marked *start*, *stop* and *slow*. This push-button station can be arranged for suspension by a flexible cord, and used as a pendant switch as shown in Fig. 8. The controller is non-reversing and is provided with current limit acceleration. If it is necessary to reverse the lathe for any purpose, it can be done by means of the knife switch shown at the bottom of the panel in Fig. 5. In the cover of the panel is located the field rheostat with the handle projecting to the outside. In turning up a large wheel, hard spots are often en-

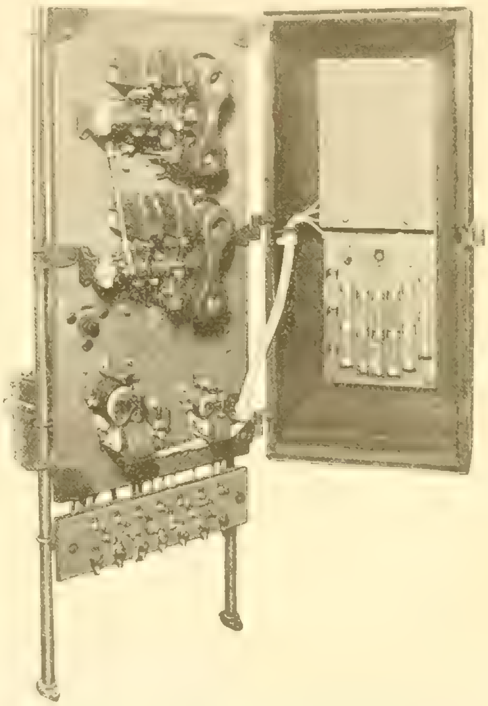


FIG. 11—REVERSIBLE PLANER CONTROLLER

For use with adjustable speed direct-current motors. The field rheostats are mounted inside the cover and operated from the handles on the face of the cover as shown in Fig. 10. One rheostat is for the cutting stroke and the other for the return stroke.

countered requiring a slow cut over a part of the circumference. This can be obtained by depressing the button marked *slow*. "Inching" of the motor can be obtained by manipulating the *start* and *stop* buttons. This is very desirable in setting up work.

PLANER CONTROL

When a reversible motor is used for driving a planer, Fig. 10, the motor must be stopped and started quickly in the reverse direction. This requires a special motor, as well as a special controller. It is desirable to have a motor which gives a large torque with a small diameter of armature. The work done in reversing the platen of the planer consists in dissipating the stored energy in the moving parts until the platen comes to rest, and then storing energy in the moving parts dur-

ing acceleration in the reverse direction. As the planer platen moves slowly, it has very little stored energy. Most of the energy stored is in the motor armature; hence the larger the diameter of the armature, the more work must be done in reversing. This requirement has resulted in the production of motors designed for this

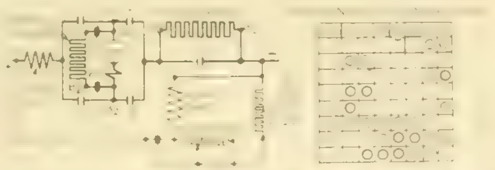


FIG. 12—[illegible]

Shown in Fig. 11.

particular service and known as planer motors. These motors usually have a speed adjustment of 4:1 by shunt field control. Two field rheostats are used, one of which controls the speed during the cutting stroke and the other rheostat during the return stroke. An arrangement of this kind is necessary so that the adjustment of the cutting stroke to suit the work will not interfere with the speed of return. During the stopping and acceleration period, both field rheostats are short-circuited automatically to give the motor the maximum torque during this part of the cycle.

A master switch, as shown in Fig. 9, is located on one side of the planer and operated by a shifting mechanism controlled by projections from the platen of the planer. These projections or "dogs", can be adjusted to limit the travel of the platen in each direction. The master switch is operated like the belt shifting device on the old planers. Sometimes this master switch has been combined with a switch for reversing the direction of the motor. This caused considerable arcing

FIG. 13—GROUP OF WOOD TURNING LATHES

Equipped with four-speed, squirrel-cage motors which are totally enclosed and operated by drum-type controllers. These controllers are located back of the leg of the lathe with their operating handles near the head of the lathe.

in this switch and therefore much better service can be obtained by using magnet contactors for switching the motor circuit and using the master switch only for the purpose of controlling the small wire circuits to the contactor.

Controllers for planer service require rapid acceleration and therefore the starting resistance is short-circuited in one or two steps. Even with a 150 horsepower motor, starting in one step has been found to give the best results when the motor and control are adapted for such operation. When it is realized that the platen of the planer may pass through the cutting and return stroke, making a complete cycle in six or seven seconds, the speed of stopping and accelerating is very important.

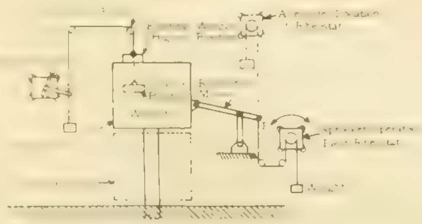


FIG. 14—ARRANGEMENT OF CONTROLLER FOR A HYDRAULIC ACCUMULATOR

For use in forge shops.

It is desirable to provide for an emergency stop in case of failure of voltage. A common method of obtaining this is to short-circuit the motor armature through a resistance and at the same time short-circuit the field rheostat. This causes the motor to operate as a self-excited shunt generator. Usually there is sufficient residual magnetism in the motor field to make this operation satisfactory. Where it is necessary to take extra precaution, a mechanical brake with a magnetic release can be mounted on an extension of the motor shaft. The magnet windings are energized by line voltage to release the brake, therefore on failure of line voltage the brake sets. The brake wheel adds to the stored energy of the armature of the motor; the magnet

FIG. 15—ELECTRICALLY-OPERATED SLOTTER

Driven by a 20 hp, 4:1 reversing planer motor. The controller used is similar to that shown in Fig. 11.

winding consumes energy while the planer is operating; the brake itself takes up extra room and requires a special extension of the motor shaft. For these reasons, the brake is not used except where it is important to make a positive emergency stop.

Fig. 12 shows a wiring diagram and Fig. 11, a standard control panel which has had a wide application. This panel provides for dynamic braking by connecting the motor as a self-excited shunt generator in case of the failure of line voltage. The direction of rotation of the motor is controlled by double-pole magnetic contactors, shown at the top of the panel on Fig. 11. The contactors are interlocked by a steel rod, which prevents both directional switches being closed at the same time. Each directional switch is provided with a back contact shown as *1A* and *2A* on the diagram in Fig. 12, which complete the dynamic brake circuit. When either directional switch is closed, this back contact is opened, disconnecting the brake circuit. The shunt field remains connected across the line when the planer is being operated. It is provided with two field rheostats, only one of which is shown on the diagram, one rheostat being for forward operation and the other for reverse operation. The particular rheostat in use is selected by the master switch. Connections are

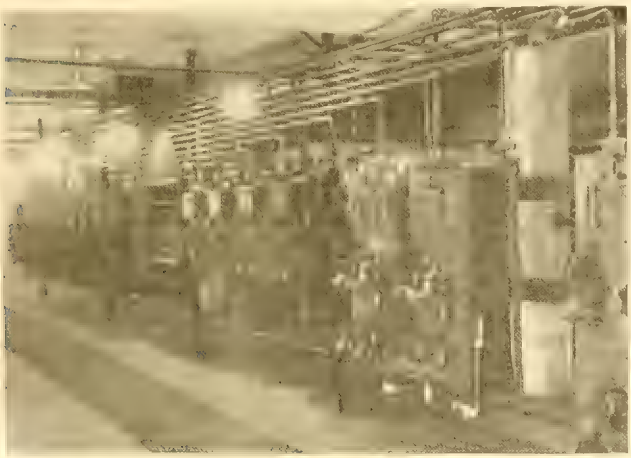


FIG. 10—METHOD OF GROUPING MACHINE TOOL CONTROLLERS

On either side of the distributing cabinet. If this row of controllers is protected by a screen, it will meet safety requirements, as the operation of the motor is by a push-button or master switch and the operator is not required to handle any apparatus on the control panel.

arranged so that these field rheostats are short-circuited during acceleration by means of a contact attached to the accelerating contact *5* in Fig. 12. The small contactor in the lower right-hand side of the panel is used for no voltage protection. On failure of voltage, the planer is stopped and cannot start again until the reset button is operated.

In addition to a master switch operated by the platen of the planer, a pendant switch, Fig. 8, may be provided having push buttons marked *master*, *pendant*, *cut* and *return*. When the *master* button is pressed, the master switch controls the operation; when the button marked pendant is pressed, the operation is controlled by depressing either the *cut* or *return* button. It is necessary to hold these buttons down, so that the motor will come to rest automatically if the operator releases the pendant switch. In addition to these buttons, the reset button may be included in the pendant switch. The use of this pendant switch adds greatly to the convenience of the operator in setting up his work.

As an added precaution, the master switch is wired so that both sides of the operating coils are disconnected when the switch is in the *off* position. In

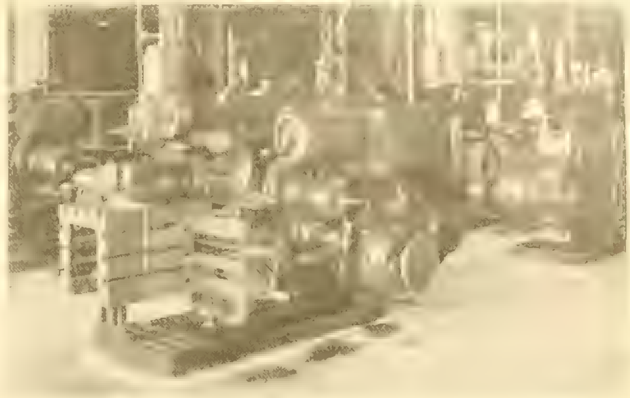


FIG. 17—MOTOR-DRIVEN SHAPER WITH DRUM CONTROLLER

Having armature starting and field regulation, showing a neat and compact arrangement for electric drive.

designing controllers, it is desirable to eliminate as many interlocks and relays as possible.

The planer type of control has been used with slotters, Fig. 15, planers, shapers, key seaters, and gear-cutting machinery. Each of these applications differs to some extent from the standard planer, and it is not desirable to apply a standard controller without an investigation. This is particularly true in the application to gear cutting machinery. Some of these machines oscillate the gear, and at the same time move the tool forward and back. If the gear is very heavy, the rapid oscillation of this gear imposes a severe duty upon the whole equipment and care must be taken to prevent seriously racking the apparatus.

FIG. 18—PLANER WITH AUTOSTARTER AND CONTINUOUSLY OPERATING ALTERNATING-CURRENT MOTOR

The reversing of the platen is done by shifting belts. This makes a very good arrangement for alternating-current drive. The guard on the side of the planer serves to prevent injury to the operator.

A modification of the reversing planer equipment is the non-reversing equipment. The direction in which the platen travels is changed by mechanical means and the motor permitted to run continuously in one direction. Provision, however, is made for changing the

speed of this motor by adjusting the field so that a different speed of platen can be used for the cutting and return strokes. This equipment permits the use of a standard motor, but in many respects is not as economical as the reversing equipment and sometimes difficulty is experienced with the mechanical reversing drive, due to wear. Such an arrangement, however, lends itself readily for attachment to standard planers, formerly designed for line shaft drive.

The development of the wheel lathe and the planer controllers shows the advantage of electric drive for machine tools where a proper equipment is designed and the machine tool built for such an equipment. Many special machine tools are being designed for motor drive; if a proper study of the conditions is made, present experience in this art enables the electrical engineer to provide a suitable equipment to meet the most exacting conditions.

Periodical Insulation Tests

P. M. Lincoln

An EDITORIAL in the October, 1917, issue of the Journal, under the above caption, raised the question as to the proper tests to apply to electrical apparatus after it had seen actual service. The following brief questionaire was attached to that editorial:—

1—What companies apply potential tests to the insulation of their generators and other similar apparatus?

2—How frequently is such a potential test applied?

3—What test voltage is applied (measured in terms of normal operating voltage)?

This questionaire has brought forth eighty replies, scattered among public service companies of twenty-seven states in all parts of the country. In the present article a brief summary is made of these replies, as well as some further comment upon the general subject.

Of the eighty replies received, seventy-five admit, more or less frankly, that no attempt has been made to apply periodical high potential tests to generators and other apparatus for the purpose of determining the condition of the insulation after the apparatus had once been placed in regular service. In many instances, this generalization was modified by the statement that the apparatus was given a potential test when new, or after repairs, or when there was any good reason to suspect the integrity of the insulation. Five companies out of the eighty reported that periodical potential tests were applied. These five cases are of sufficient interest, we believe, to give their practices in more or less detail.

The Commonwealth Edison Company, of Chicago, Ill., probably have the most comprehensive schedule of tests which has so far been adopted. This Company applies a high potential test to their apparatus once a year, after the regular annual over-hauling and cleaning. The schedule of tests that are applied to various classes of apparatus is as follows:—

CLASS OF APPARATUS	COMMONWEALTH EDISON CO., STANDARD ALTERNATING-CURRENT TESTS ON NEW AND OLD APPARATUS.	A. I. E. E. RULES
Generators		
Armatures (*new*)	Twice the normal voltage of the circuit to which it is connected, plus 1000 volts, (1 minute.)	A. I. E. E. rules
Armatures (*old*)	4500 volt armatures, test at 10 000 volts, 30 seconds.	No rule
	9000 volt armatures, test at 15 000 volts, 30 seconds.	No rule
	12 000 volt armatures, test at 18 000 volts, 30 seconds.	No rule
Fields (*new*)	110 volt excitation, test at 1500 volts, (1 minute). 220 volt excitation, test at 2500 volts, (1 minute). To include field cables and exciter if on the generator shaft.	Ten times the exciter voltage but in no case less than 1500 or more than 3500 volts
Fields (*old*)	110 volt excitation, 1200 volts (1 minute).	No rule
	220 volt excitation, 2000 volts (1 minute).	No rule
High-tension busses	Twice the normal operating voltage, plus 2000 volts, (1 minute).	No rule
Exciter Busses	1500 volts, (1 minute).	No rule
Exciters 110 volts	1500 volts (1 minute). To include armature, field cables and all connected apparatus.	No rule
Transformers	Twice the normal voltage of the circuit to which it is connected, both primary and secondary windings, (1 minute), in no case less than 1500 volts on low voltage windings.	
Wiring	Control and secondary wiring 1500 volts, (1 minute).	No rule
Neutral Resistances	5000 volts between grids and frame, 1 minute. 10 000 volts between frame and ground, 1 minute.	

The Niagara Falls Power Company, Niagara Falls, N. Y., report the following schedule:—

"Every two weeks our 2200 volt, two-phase, generators are subjected to a breakdown test of 4000 volts for a period of five minutes. This test is between phases and between each phase and ground.

Every two weeks the 12 000 volt, three-phase generators in our Canadian plant are subjected to a breakdown test of 15 000 volts between windings and ground foi a period of five minutes."

The Interborough Rapid Transit Company, of New York state that they test their generators, cables, and high tension side of transformers at 19 000 volts to ground for two minutes. The 600 volt sides of transformers and rotary converters are tested at 2000 volts, two minutes. These tests are applied annually after the regular summer overhauling. The high tension side of this system is operated at 11 000 volts.

In this connection, in a letter dated July 11, 1910, the late Mr. H. G. Stott informed the writer that at that time it was the custom of this company to apply a 22 000 volt test to ground on their high tension apparatus, and 2500 volt test to ground on the 600 volt apparatus, instead of the figures given above. Presumably the lowered test voltage has been adopted on account of the aging of the insulation since 1910.

The Edison Electric Illuminating Company of Brooklyn report that they apply a potential test to their generators once a month and that the value of the test is 150 percent of normal operating voltage for five minutes. Their operating voltage is 6600 volts and they report no insulation breakdown from these tests.

The Philadelphia Rapid Transit Company report:—

"Our generating stations are equipped with special testing equipment and the necessary bus-bar and switching arrangements for applying variable voltage tests to all parts of the alternating-current generator windings and underground cable system. These tests are made at regular intervals; the voltage being brought from zero to a value not exceeding 10 percent above normal.

The length of the time between tests varies with the different types of equipment. On some types of apparatus, the tests are made monthly, on others, particularly our high tension feeders, the tests are made approximately every three months.

Particular attention is given to the tests of insulation resistance on all alternating-current generator field circuits. These tests are made with a standard 1000 volt "Megger" and the results are carefully plotted on record cards. This information serves as a very accurate indication of the condition of our field insulation and has proven of considerable value in the operation of our generating units."

The foregoing companies are the only ones that have reported making potential tests periodically with a view of determining the condition of the insulation. The smallness of the number of companies making such tests, as well as the wide variation of their practice, makes it difficult to suggest a standard practice either in regard to the value of the voltage to be applied, the time of this application, or how frequently to apply the test. Another consideration, which makes it difficult, if not impossible, to suggest the standardization of such tests, is that they must always be made with a view to the local conditions which dictate the time of the year or day when a given unit can be spared for a long enough period to make repairs, should the application of such a test result in the breaking down of the insulation. This is a matter which must, of course, be governed in each case by local conditions.

About twenty percent of the companies replying to the questionaire state that they test the insulation of their generators and other apparatus periodically with a "Megger" or with some other device which shows the value of the insulation resistance. Some companies state that all of their determinations upon the condition of insulation are made in this manner. This serves to raise again the question as to the worth of insulation resistance as a measure of the ability of insulation to withstand the stresses due to normal operation.

As pointed out in the October 1917 editorial, there are a number of things that cause insulation to deteriorate. "Deterioration of insulation may occur from mechanical shock or rupture, vibration, moisture, heat —all may contribute to this deterioration and at a rate impossible to predetermine. So far as we know there is no infallible method of determining the condition of insulation without actually applying a potential test. The megger or any other means of determining insulation resistance gives an indication of some value, but it is possible for the insulation to show satisfactory resistance and still be on the verge of a breakdown under normal operation."

Further, insulation resistance is in general simply a measure of the quantity and temperature of the moisture content of insulation. This quantity may vary over wide limits and this variation may occur without endangering in any way the integrity of the insulation. As a measure of the ability of insulation to stand the stresses of normal operation, therefore, the determination of insulation resistance leaves much to be desired. We see no method of making an adequate determination of the ability of insulation to stand up under normal operating conditions without applying an actual potential test on the insulation. While it is unfortunate that the insulation must be subjected to the danger of breakdown in order to find out if it is in proper condition, this should not deter the operating engineer from making tests.

One thing that the study of this matter has brought out very clearly, is that there is still much to be learned concerning the question of deterioration of insulation due to normal operation of generators, transformers and the like. Operating engineers should take every occasion to increase our store of knowledge on this important matter. In this connection, an interesting suggestion has been made by Mr. S. C. Lindsay, of the Puget Sound Traction, Light & Power Company of Seattle. Mr. Lindsay suggests that each time it becomes necessary to rewind any generating or transforming apparatus, it would be highly desirable to make tests to destruction in order to determine the strength of the insulation before the winding is removed for the purpose of putting on the new windings. If this could be done every time a machine is rewound, it would result eventually in the collection of a valuable amount of data. We commend this suggestion and hope that some means can be found to carry it out.

Current Capacity of Copper Bus-Bars

F. M. Billhimer

THE EXTENT to which operating temperatures may be reduced economically by the use of large conductors and special construction will depend upon the cost of copper and the nature of the load; for example, a heavy intermittent current may often be carried by small conductors if the resultant high temperature is less objectionable than the required investment in copper necessary to secure a lower temperature.

The practice of specifying a current density for copper conductors is commonly insufficient to insure that the conductors will operate within the desired temperature limits. A better way is to state the temperature rise allowable as this quantity depends upon the current distribution within the conductor, and the readiness with which the conductor gives off its generated heat. The dissipation of heat depends upon the position with regard to other conductors, size and shape of the conductor, and upon the amount of current to be carried.

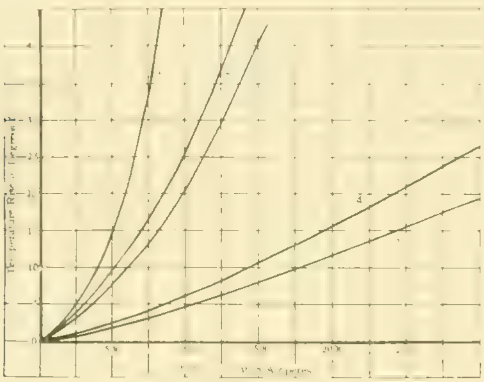


FIG. 1—EFFECT OF SPACING ON THE CURRENT-CARRYING CAPACITY OF DIRECT-CURRENT COPPER CONDUCTORS

1—1 strap, 3 inch by 1/8 inch.
2—2 straps, 3 inch by 1/8 inch with 1/8 inch spacing.
3—2 straps, 3 inch by 1/8 inch with 1/4 inch spacing.
4—8 straps, 3 inch by 1/8 inch with 1/8 inch spacing.
5—8 straps, 3 inch by 1/8 inch with 1/4 inch spacing.

DIRECT-CURRENT CONDUCTORS

Since the temperature rise of a conductor carrying a direct current depends upon the amount of surface exposed to the air and the resistance of the conductor, it is evident that a conductor large enough in cross-section to carry several thousand amperes with a given rise, can be replaced by several small conductors with a total surface greater than that of the large conductor, but with a smaller total cross-section.

Assume a relatively small increase in the thickness of a single strap conductor as compared to its width. Neglecting the slight additional radiating surface due to increasing the thickness, the current carrying capacity for a given temperature rise may be calculated as follows:—

Let $I_1^2 R$ = the watts loss in a copper strap of unit thickness for a given temperature rise, and $I_2^2 \frac{R}{2}$ = the watts loss in a copper strap of twice the thickness of the above strap, but of the same width, for the same temperature rise. Since the watts lost are the same it follows that:—

$$I_1^2 R = I_2^2 \frac{R}{2}$$

or

$$I_2^2 = \frac{2 I_1^2 R}{R}$$

Let I_1 = unity.

$$I_2 = \sqrt{2} = 1.41$$

This means that the capacity of a strap conductor is increased only 41 percent by doubling its thickness when the width remains constant. The same law applies to a conductor built up of two or more straps if little or no air space is left between the several straps, as may be seen from test results as shown on curves *1* and *2*, Fig. 1.

The current carrying capacity at 20 degrees C. rise for various thicknesses is shown in Table I.

TABLE I—CURRENT-CARRYING CAPACITY OF STRAP CONDUCTORS

Size of Bar in Inches	Capacity Factor	Amperes, Direct Current
3 by 1/8	1.00	600
3 by 1/4	1.41	846
3 by 3/8	1.73	1038
3 by 1/2	2.00	1200

As given in the above tabulation, one strap 3 by 1/8 inch will carry 600 amperes direct-current with a rise of 20 degrees C., while one 3 by 1/4 inch strap will carry only $\sqrt{2}$ times the capacity of the 1/8 inch strap, or 846 amperes. If a 3 by 3/8 inch strap be used, the current carrying capacity will be $\sqrt{3}$ times the capacity of the 1/8 inch strap. The fact that the current carrying capacity of a rectangular copper strap varies directly with the width and not directly as the thickness of the strap for a given temperature rise may be further illustrated by considering two 3 by 1/8 inch copper bars placed edge to edge, making an equivalent 6 by 1/8 inch bar. The current carrying capacity of this arrangement is twice the capacity of one bar. Two such straps placed side by side without leaving any air space between them are the equivalent of a 3 by 1/4 inch bar with one-half the resistance of one 1/8 inch bar, and have a carrying capacity of 1.41 times that of one 3 by 1/8 inch copper bar.

The question of spacing, where straps are used in multiple to form a bus-bar or heavy capacity conductor, is worthy of careful consideration since a spacing of the several straps 1/4 inch instead of 1/8 inch will often mean a considerable reduction in the operating temperature. Curves *2*, *3*, *4* and *5* of Fig. 1 illustrate this point for two different sizes of conductors. Spacings of 1/2 inch or greater would of course be advisable in

some instances where the space occupied by the conductor is not limited and the temperature rise with the smaller spacing would be objectionable.

ALTERNATING-CURRENT CONDUCTORS

The problems which are encountered in the application of conductors to direct-current circuits also apply to alternating-current circuits, but in addition to the limits which resistance, shape and spacing place upon the capacity of the direct-current conductor, skin effect and mutual induction must also be considered, as these factors cause non-uniform current distribution in the alternating-current conductor.

If the conductor has a large cross-section, the alternating magnetic field, in cutting the conductor, will set up differences of potential between the different parts of the conductor, thus causing local or eddy currents in the copper. The alternating-current in the conductor produces a magnetic field inside as well as outside of the conductor, and the lines of magnetic force

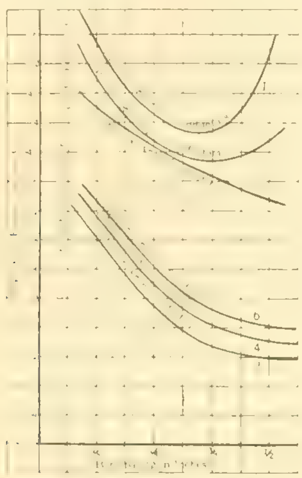


FIG. 2—VARIATION OF TEMPERATURE WITH DIFFERENT BAR SPACINGS

In a conductor composed of eight 3 by 1/8 inch copper bars carrying 3000 amperes of 60 cycle current

which close themselves inside of the conductor generate electromotive forces in their interior only. The counter e.m.f. of self-induction is therefore largest at the conductor axis and least at the surface; with the result that the current density is greater at the surface than at the center of the conductor.

In practice this phenomenon becomes more pronounced at the higher frequencies. The difficulties are often avoided by using a shape of conductor such that unequal current distribution is reduced to such an extent that it is not objectionable, through the use of a tubular or flat conductor, or several conductors in parallel.

The selection of suitable conductors for use on alternating-current circuits of high or even 25 or 60 cycles has received considerable attention during the last few years, due to the fact that heavy current installations are becoming quite numerous. In fact, the need of a careful survey of each high current proposition is imperative in order that unnecessary expense may be avoided by placing copper where it will do the most good.

The results of some single phase 60 cycle tests made on a conductor composed of eight 3 by 1/8 inch copper bars carrying 3000 amperes are given in Fig. 2. The temperatures resulting from different spacings of the bars of the conductor, and different spacings of the

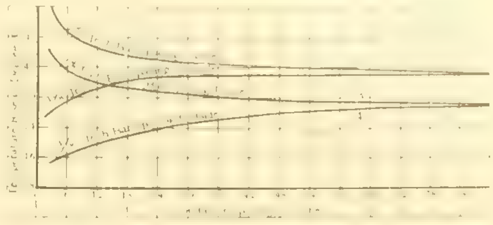


FIG. 3—VARIATION OF TEMPERATURE WITH SPACING OF TWO CONDUCTORS

As shown in Fig. 4. Each conductor consists of eight 3 by 1/8 inch copper bars and carries 3000 amperes of 60 cycle current.

conductor from its return circuit, show the combined effect of the self-induction of the individual conductors and of the mutual induction of the two conductors under the several conditions.

The effect of self induction is to cause most of the current of the individual conductors to be forced to the surface of the conductor, while mutual induction causes a non-uniform distribution of current such that the side of the conductor adjacent to the conductor of opposite instantaneous polarity has a higher current density than the outer portion of the conductors, thus causing excessive heating of the inner side of the conductor.

Curves *1* and *2* of Fig. 2, show that there is a temperature difference of 30 degrees C. between the outside and the inside bars of the conductor for the 3/8 inch spacing of bars, when the conductors are spaced three inches apart between adjacent sides of the conductor and its return circuit. This difference of temperature decreases to 23 degrees for a six inch spacing of conductors and to 19 degrees for a nine inch spacing of the

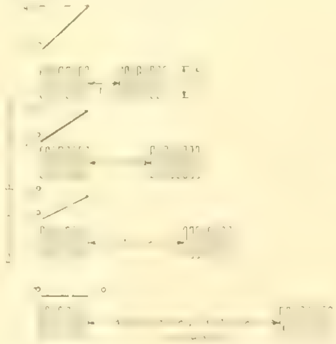


FIG. 4—RELATIVE POSITION OF CONDUCTORS

Composed of eight 3 by 1/8 inch copper bars with 3/8 inch spacing between individual bars.

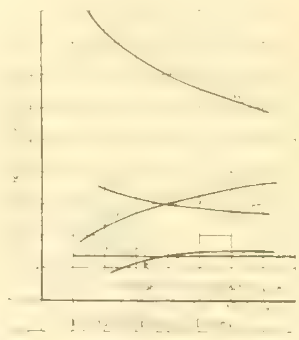


FIG. 5—EFFECT OF SPACING ON CURRENT-CARRYING CAPACITY OF CONDUCTORS

For 60 cycle, 25 cycle and direct-current.

conductors. Curves *3* and *4* of Fig. 3 illustrate the gradual decrease in this difference if the conductors are further removed, until the resultant temperature finally is uniform for the inner and outer sides of the conductor while carrying 3000 amperes at 60 cycles. The posi-

tions of the conductors with reference to their return circuits are shown in Fig. 4 for the ⅜ inch spacing of individual bars.

Curves *1* and *2*, Fig. 3 show a decrease of the effect of mutual induction as the conductors are separated. They also well illustrate the fact that the conductor with ⅛ inch spacing of bars has less opportunity for dissipating its heat and therefore has a higher final temperature than the conductor with ⅜ inch spacing of its bars.

A comparison of the current carrying capacity of a conductor influenced by its return circuit at various spacings and carrying 60 cycle, 25 cycle, and direct current is shown on Fig. 5. The reduction in temperature with increased distances between conductors for uniform bar intervals is also shown in the 60 cycle and 25 cycle curves.

The foregoing discussion points out in a general way the factors which influence the energy loss in direct and alternating-current conductors. For laminated bar conductors arranged with vent ducts and carrying alternating currents, the current distribution will, in general, be made as nearly uniform as possible by separating the conductors as far as practicable and making the thickness of the conductor a minimum. For mechanical reasons the thickness of individual bars cannot be reduced too far.

In general, no exceptional mechanical difficulties should be encountered in handling currents of 2000 or 3000 amperes. Where very heavy currents are to be handled, the design of conductors for direct current demands careful consideration, while for alternating currents the design is difficult, involving not only mechanical means of support but also current distribution. The current distribution is, in turn, controlled by the frequency of the circuit, volume of current, form and size of conductors, as well as their positions with respect to each other.

The Action of Dirt on Railway Motor Carbons

J. S. Dean

A CAREFUL examination of railway motor carbon brushes that have been in service for some time will show peculiar streaks or grooves running along their front and back surfaces. Sometimes these streaks are nearly parallel, running lengthwise along the side of the carbon, and in other instances they are very irregular, branching out in a number of directions with the characteristics of lightning streaks. It seems to be the general consensus of opinion of those familiar with these markings, that they are due to side burning of the carbon, caused by the passage of a current either from the carbon to the box, or from the box to the carbon.

Some interesting tests have been made in connection with railway motor carbons which throw light on this subject. These tests were performed with the following apparatus and operating conditions:—

Carbons—Six different grades—all new.
Two carbons per brushholder—initial length two inches.

Brushholders—Two per motor—all new.

Motors—Non-ventilated type—Commutating-pole.
Top commutator cover off.
Assembled on car as No. 2 motor.
Mounted with commutator opening directly under trap door in car floor.

Cars—Quadruple equipment—double end operation.
Inspection trap doors in car floor.

Service—City.

Road bed—Paved streets.

Time of year—Summer with dust and dirt present.

The primary object of these tests was to get some comparative data on the life of various grades of carbons. During the progress of the work of inspection of carbons for end wear, side wear, breakage, etc., a rather common pronounced streaking of all test carbons was noticed, which at first thought was attributed to arcing or burning of the carbon due to the current passing from the carbon to the side of the carbon box. A very striking example of this marking is shown in Fig. 1 (a). Further study of this streaking on a number of samples lead to the assumption that this marking was probably due to particles of sand and dirt working their way down between the side of the carbon and carbon box which, by constant vibration, movement of the carbon and the action of gravity, cut small grooves in the sides of the carbon. The reasoning leading up to this hypothesis was based on the following:

1—*The Condition of the Inside of the Motors*—There was evidence on the inside of the motors of the presence of considerable dust and dirt. The brushholder castings were dirty and a lining of fine dust and dirt had collected on the inside of the motor frame and on the windings.

2—*The Position of the Brushholders in the Motor Frame*—The brushholders were located directly under the commutator opening in the frame, as shown in Fig. 5. With the commutator lid off, any dust or dirt from the street or from the car floor through cracks at the trap door, drops into the openings and a portion of it lodges on the brushholders and carbons. The particles that lodge on the front opening of the carbon box, form the grooves on the front side of the carbons, while those that lodge on top of the carbons (which were two inches long and did not extend above top of carbon box) worked in between the carbons and the rear support on the carbon box, and formed the grooves on the back side of the carbon.

3—*The Location of the Streaks on the Carbons*—Fig. 1, which is a good example of this streaking, shows that at the front of the carbon the streaks start at a point on the carbon which coincides with the end of the opening (made for the pressure finger) in the front of the carbon box, and extends on the carbon a width corresponding to the width of this opening. On the rear, they are found only at the points where the carbon box supports come in contact with the carbon. The general direction of all these streaks is parallel to the length of the carbon.

4—*Similar Markings on All Grades of Carbon*—This phenomenon was noted and studied on six different grades of carbons. If it was burning and arcing due to the passage of electric current from carbon to carbon box that caused this streaking, some noticeable difference in the degree of this marking would be expected due to the composition and inherent properties of the various grades of carbons; but this was not apparent.

5—*The Condition of the Inside of the Carbon Box*—As all new brushholders were used during these tests, if there was

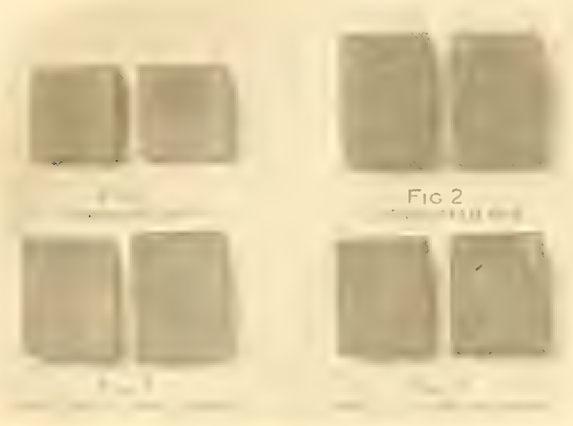
any appreciable arcing between carbon and carbon box, it would have been detected on the surface of the inside of the carbon box. However, no evidence of burning could be found.

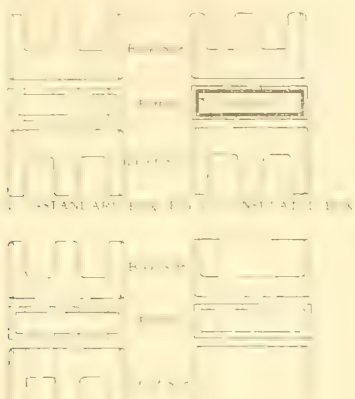
6—*A Close Inspection of the Grooves* on one of the sample carbons taken from service revealed, by means of a magnifying glass, several small particles of sand imbedded in the grooves.

With this information at hand, several tests were outlined and made on special brushholders to try and confirm this dust and dirt theory. The results obtained from these tests are given in detail below:—

1—*A Standard Brushholder* with the regulation size carbon box, Fig. 1 (c), was put in service to be used as a standard for making comparisons of streaking on the sides of the carbons. After approximately three months service, these carbons were removed and, as shown in Fig. 1 (a) and (b), show pronounced streaking, both front and back.

2—*Brushholder with Insulated Box*—A standard type brushholder was taken and the box machined one-thirty-second inch larger all around, and a strip of insulating material was cemented on the inside, as shown in Fig. 2 (c), to prevent a flow of current from the carbon to the carbon box. This brushholder was put in service, using standard carbons. After about two months service their appearance was as shown in Fig. 2 (a) and (b). These carbons show the same characteristic streaking as was obtained with a standard carbon box.





FIGS. 1 to 4(c)—MODIFICATIONS OF BRUSHHOLDERS

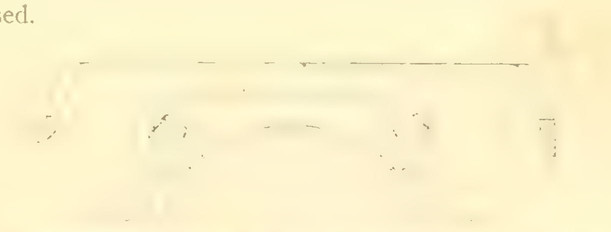
As it was impossible for the current to travel from the carbon to the carbon box on account of the insulating material, this streaking was obviously due to some other cause rather than burning by an electric current.

3—*Brushholder with Box Grooved*—A standard brushholder was taken and a groove one-sixteenth inch deep, beginning at the end of the opening in box for the pressure finger, was machined at the left front end opening of the box. This groove was made the width of the opening and extended down to the bottom of the box to allow a free passage for the particles of dust and dirt that collect on this ledge of the carbon box and work their way down between the carbon and the box. That part of the carbon box for the right hand carbon was left unchanged. The carbons from this brushholder were removed from service after about two months and are shown in Fig. 3 (a) and (b). The right carbon from the unmachined side of the box shows the same general streaking, front and back, while the left carbon taken from the grooved side shows no streaking at the front but is streaked on the back in a manner similar to the other carbon. The evidence in this case shows the presence of dust and dirt with

its pronounced markings on the carbons in the same characteristic manner, except at the point where sufficient clearance was allowed for it to pass between the carbon and the box without any obstruction.

4—*Brushholder Box with Closed Front and Opened Back*—A modified type brushholder with special pressure fingers was constructed, having the front of the box entirely closed and the rear of box entirely cut away for a distance of about three-quarters of an inch from the top, Fig. 4 (c). This construction was intended to do away with the ledge at the front end of the box and the support at the rear end of the box that extended above the top of the carbon, so that there was no place for dirt to collect between the carbon and the front side of the carbon box. All dirt that lodged on the top of the carbon could slide off and would not be held there to work down between the carbon and the back carbon box supports. Fig. 4 (a) and (b) shows that these carbons after eight weeks service have no indications of streaking, which proves the effectiveness of properly protecting the sides of the carbons from the entrance of dust and dirt.

A resume of the above results gives the following definite facts upon which a final conclusion can be based.



1—Pronounced streaking of carbons exists.
2—Streaking was produced when electric current was not present.
3—Considerable dust and dirt was in evidence.
4—When dust and dirt chutes were provided, no streaking was produced.
5—When the dust and dirt were diverted, streaking was eliminated.
6—Sand particles were found lodged in groove.

The above is convincing evidence that this grooving or streaking of railway motor carbons is due to the action of dust and dirt working its way down between the carbon and carbon box.

The Essentials of Transformer Practice - VIII

Properties of Insulating Materials

E. G. Reed

THE STUDY of the insulation of a transformer as a whole should be preceded by a separate examination of the properties of the insulating materials used, just as an acquaintance with the properties of copper and magnetic steel must accompany a thorough knowledge of the transformer.

Some of the properties of an ideal dielectric would be infinite resistance and perfect elasticity, in the sense that the energy required to establish an electric field through it would be returned as the field falls to zero. In other words there would be no energy loss in the dielectric when placed in an alternating electric field and the current required to maintain the electric field would be 90 degrees from the voltage in time phase relation. Such a current would be the wattless charging current of a condenser. In an actual dielectric there is an energy loss, made up of an I^2R loss and a loss due to the imperfect elasticity of the material. The latter is in some ways analogous to the hysteresis loss in a magnetic circuit, but the analogy fails if carried too far. If a curve be plotted for such a dielectric between current and electric field intensity, a further similarity to a magnetic circuit is that the curve will have some of the characteristics of a saturation curve. The curve may be considered as being composed of three parts; first, where the current is an approximately constant function of the field intensity and second where the current is growing at an increasing rate as the field intensity increases. This part of the curve represents the condition when the material approaches its breakdown point. As the dielectric fails the current increases so rapidly that, third, the curve becomes practically parallel to the axis of current, or the saturation point is reached.

Another phase of the analogy between the dielectric and magnetic circuit is that the decreasing alternating-current resistance with increasing electric field intensity, is similar to the changing reluctance of the magnetic circuit with increasing values of the magnetizing force. The impedence of the dielectric, however, is a very much more unstable quantity than the reluctance of the magnetic circuit.

Some of the most important properties of insulating materials are as follows, though the order in which they are given is not necessarily that of their relative importance;—

1—Insulation resistance
2—Dielectric loss
3—Dielectric strength
4—Specific inductive capacity
5—Heat conductivity
6—Mechanical strength

Some of these characteristics are closely related with each other, for example the presence of moisture in the material changes its insulation resistance, its dielectric loss and to a lesser degree its dielectric strength, without greatly changing its other properties.

INSULATION RESISTANCE

The minute spaces and capillary tubes in a solid dielectric contain varying amounts of moisture and gases. A conducting path through the dielectric is made up of a complicated arrangement of resistances and capacities in series and in multiple. The resistance of a given path through the dielectric is called its insulation resistance, and the current in phase with the voltage producing the electric field is called the resistance current. Direct current is used to measure insulation resistance as the charging current with alternating current is usually relatively large and overshadows the resistance current. Energy measurements are necessary as well as voltage and current to determine the effective alternating-current resistance. Even with direct current the resistance varies with the applied voltage decreasing somewhat with increasing potential.

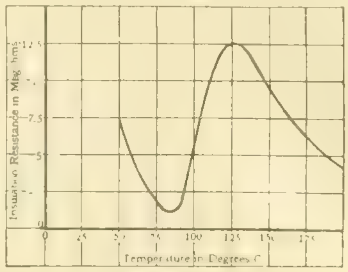


FIG. 1—VARIATION OF INSULATION RESISTANCE OF PAPER FIBER WITH TEMPERATURE

The principal conditions which influence the insulation resistance of solid dielectrics are,

1—Temperature.
2—Moisture.

Fig. 1 gives a characteristic curve for fibrous materials, such as paper and cloth, showing the variation of the resistance with temperature. The increased resistance at lower temperatures seems to be an inherent property of all insulating materials but is exaggerated by the presence of free moisture. It is probable that at the lower temperatures the moisture is in small isolated globules, which at higher temperatures vaporize and penetrate through the insulation, thus lowering its insulation resistance. The greater the amount of moisture present the greater would be the difference expected between the hot and cold resistance measurements. If a piece of insulation is gradually heated and the moisture is free to escape, the relation between the temperature and the resistance will be like that shown in Fig. 1. The resistance at first decreasing because of the moisture being vaporized and again increasing because of the vapor being expelled at the higher temperatures. If a piece of insulation is carried through a

series of such cycles, the amount of moisture remaining at the end of each cycle would become less and less. The change in the resistance between the extremes of temperature would therefore become smaller, being then largely that due to the intrinsic quality of the resistance.

After the expulsion of the moisture, the material begins to change in nature and ultimately begins to carbonize and behaves as a high-resistance conductor; the resistance then falling rapidly to a very low value. While this curve is typical of all insulating materials, the exact temperature at which the minimum and maximum values occur depend mainly on the area of the electrodes, the amount of moisture content and the facility with which it may escape, and on the chemical and physical changes that occur due to the temperature.

DIELECTRIC LOSS

In general the dielectric loss for a given material increases with

1—Voltage
2—Moisture
3—Temperature
4—Frequency

The variation of the dielectric loss for dry, oil saturated, insulating board is shown in Fig. 2* expressed in watts per cubic centimeter, with the field intensity expressed in kilovolts per centimeter. The power-factor curve is also given, and the low values mean that there is very little I^2R loss in the material, which in turn indicates that there is not much moisture present. The absorption of a slight amount of moisture would greatly increase the I^2R loss and consequently increase the power-factor. When the dielectric loss is largely I^2R loss due to the presence of moisture, the power-factor increases with increase of the electric field intensity, because the increase in the I^2R part more than overbalances the increase in the so-called hysteretic element. On the other hand, with dry material the increase of the hysteretic element of the loss may overshadow the I^2R loss and the power-factor would then decrease with increase of the field intensity.

The reason for the increased loss at higher temperature is largely due to the reduced resistance caused by the increase in temperature. This increase is therefore more marked with materials which contain a considerable amount of moisture.

The dielectric loss varies with the frequency, the hysteretic element being approximately proportional to the frequency and the I^2R element, of course, being constant. If the material contains moisture and is operated at a fairly high temperature, the I^2R element of the loss will overshadow the hysteretic element and the loss for 25 and 60 cycles will not be far apart. If on the other hand the hysteretic element is comparatively large a greater percentage difference will exist between the 25 and 60 cycle dielectric loss measurements.

For dry material where the I^2R element of the loss is smaller, the dielectric loss in watts per cubic centimeter for a given temperature may be approximately expressed by the relation,

$$\frac{Watts}{Cubic\ Centimeter} = KfE^2 \qquad (1)$$

where K is a constant which varies with the insulating material and the temperature at which it operates, f is the frequency in cycles per second and E is the voltage in kilovolts. For the curve shown in Fig. 2 and for a temperature of 100 degrees C., K has a value of approximately 8.5×10^{-8}. If the material contains moisture, the rate of increase of the total loss will vary greatly, and may for a limited range increase approximately as the square of the frequency.

When the dielectric loss ceases to increase approximately as some constant function of the field intensity, the approaching breakdown of the dielectric is indicated. This disclosure of the loss measurements is of more importance than the actual value of the loss in watts. The particular value of the dielectric loss measurement is to determine what conditions or treatment will permit the highest possible value of the field intensity in a given material, without approaching the critical value.

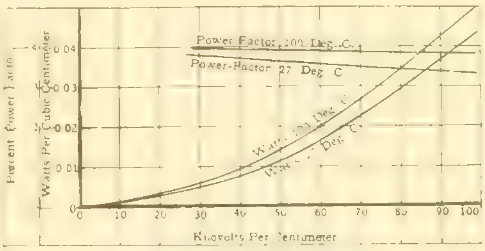


FIG. 2—VARIATION OF DIELECTRIC LOSS OF DRY, OIL-SATURATED FULLERBOARD WITH FIELD INTENSITY AT 60 CYCLES

The sheet was tested in oil immediately after being dried and saturated with oil by the vacuum-pressure method.

DIELECTRIC STRENGTH

The main factors affecting the dielectric strength of materials for a given electric field intensity are:—

1—Temperature.
2—Chemical change.

Apparently the failure of a dielectric under electrostatic stress is because the material is stressed to such a degree that it is mechanically ruptured. An example of a case where there is little change of the material except that resulting from the stress, is the breakdown of clean dry oil. Usually the breakdown in solid materials occurs at a temperature which has itself caused some deterioration and thus makes possible the mechanical rupture at a voltage which would not otherwise have caused injury. The temperature may result from the dielectric being heated from an outside source, or from the dielectric loss within the material. An example of this type of failure would be that of paper fiber under conditions where the heat from the dielectric loss could not be readily dissipated. The temperature of the dielectric would continue to rise, with a fixed impressed voltage, until the material had become so injured that failure might occur. In other words, the temperature conditions are cumulative, and a volt-

*See article on "Dielectric Losses in Insulating Materials" by Mr. C. E. Skinner, in the JOURNAL for July '17, p. 260.

age which would not breakdown the material in a short time, might do so if continued for a longer period. There also may be a condition analogous to the fatigue of materials when subjected to alternating mechanical

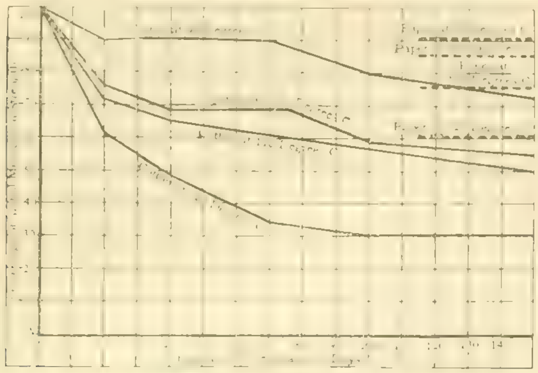


FIG. 3—EFFECT OF TEMPERATURE ON THE MECHANICAL STRENGTH OF PAPER AND COTTON FIBER HEATED UNDER OIL

stresses, which has an influence on the diminution of the dielectric strength with increased time of application of the testing voltage.

Thus all factors which affect the dielectric loss and the rate of dissipation of the heat would have an influence on the exact value of the breakdown voltage. With a low dielectric loss and good conditions for dissipating the heat, the question of the length of time the voltage is applied will have a relatively small affect. Therefore, the effect of time is more marked with thick masses of material and in such cases there is an apparent reduction in the dielectric strength with an increase of the thickness of the material. The frequency of the alternating voltage affects the dielectric value somewhat, mainly through change in the dielectric loss. Surges caused by switching or lightning, whose voltage is many times higher than the breakdown voltage of the insulation may be applied without rupture if the time period is very short. If the voltages are sufficiently high, rupture may occur at once, and if the voltage is higher than the 60 cycle breakdown voltage, the insulation will be damaged probably by mechanical tearing. The effect is cumulative and a sufficient number of such surges will cause a breakdown. The shorter the time of application, the greater the number of surges required to cause a breakdown at a given voltage. The insulation of transformers is often gradually destroyed in this way by lightning, each stroke contributing toward breakdown, probably by extending local ruptures.

If the material contains oxidizable substances or chemically unstable matter, the breakdown may be the result of chemical change. In most commercial insulating materials, it is probable that all of these conditions affect the disruptive voltage.

There are a number of other minor factors which have an influence on the dielectric values, for example the nature of the surrounding medium, size and shape of the electrodes, and time-rate of application of the disruptive voltage. Tests are useless for comparing insulating strength values unless made upon some definite basis.

SPECIFIC INDUCTIVE CAPACITY

Since a good dielectric should have a low charging current, it follows that it would also have a low specific inductive capacity. With two dielectrics in series, across which voltage is impressed, the voltage across each will be inversely as the dielectric constants of the two materials. When several dielectrics are used in series, the one having the lowest dielectric constant takes more than its proper share of the total voltage, and if it also has a low dielectric strength it may break down, even if it would have been strong enough without the presence of the other material. Thus placing a plate of glass between two electrodes will cause a spark to pass through the remaining air with a lower voltage than would be required to produce a spark in the absence of the glass. This fact is of special importance in high-voltage work, for air has both a lower dielectric constant and a lower dielectric strength than solid insulating material. Air bubbles reduce the effective dielectric strength, and may with alternating voltage contain corona which will soon damage the solid dielectric. For this reason, air should be excluded from the insulation of coils designed for high voltages, either by impregnating them with a suitable solid compound or by using them immersed in insulating oil.

The dielectric constants of some of the common insulating materials, are

Material	Dielectric Constant
Oil	2 to 2.5
Dry paper	2.6
Mica	5 to 7

MECHANICAL STRENGTH*

The curves, Fig. 3, show that the mechanical strength of paper and cotton fiber tend to reach a constant value after prolonged heating in oil at a definite temperature. Fig. 4 shows the mechanical strength of the insulation as a variable dependent on the temperature.

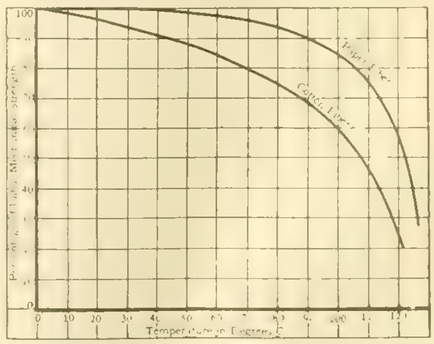


FIG. 4—EFFECT OF DIFFERENT TEMPERATURES ON THE MECHANICAL STRENGTH OF PAPER AND COTTON FIBER

The temperature conditions were continued until the mechanical strength showed no further change.

*See *The London Electrician* for July 20, 1917.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

MARCH 1918

Oil, Grease and Waste for Railway Motors and Gears

Hot bearings are due to a large extent, to poor lubrication or to an inferior grade of lubricant. The fundamentals of correct lubrication are the use of the right lubricant, applied in the right way, and in the right amount. The amount and application of lubricant depend largely upon the design of the bearing and the service conditions.*

OIL

Grade—Oils are either animal, vegetable or mineral. For railway work use a good grade of neutral mineral oil. It must be free from acid or alkali, either of which will corrode the bright surface of the metal.

Clean—The oil should be free from dirt and water. Water will reduce the lubricating value of the oil as it tends to wipe the oil from the journal. Particles of dirt and grit will increase the friction, and cause the bearings to heat up.

Fluidity—The oil should flow readily and be taken up by the waste and held. If it is too thin, the waste and bearing will rapidly drain the oil, and the bearing will soon run dry; thus, the oil must have enough body to cling to the waste and be fed to the bearings as required. It should be heavy enough to furnish a supporting film between the journal and the bearing to sustain the load. For this reason a light or thin oil, should be used in winter and a heavy or thick oil in summer.

The Oil Should Not Gum, as it will then clog up the lifting or wick action of the waste and tend to prevent the oil from entering between the journal and bearing surface.

Cost—Quality of oil should never be sacrificed to first cost. Tests to determine the quality and lubricating properties of an oil require an extensive laboratory equipment, hence to safeguard your interests always deal with reliable producers who have had years of experience and test facilities which permit them to guarantee the uniformity and reliability of their product.

SPECIAL LUBRICANTS

Special prepared lubricants which are not entirely oils are used by some operating companies with very good results, and are highly recommended.

GREASE

Uses—Grease is used in connection with the lubrication of some of the old type railway motor bearings and on all main motor gears and pinions. The same grade of grease selected for motor bearings can be used for the gears and pinions, but some special greases and compounds prepared for gears and pinions are not suitable for motor bearings, on account of their high melting point.

Grades—Grease consists of a fatty soap impregnated with a mineral oil. The solid part simply acts as a carrier for holding the oil in position, and has little value as a lubricant. Greases are usually graded according to their stiffness, which has an important bearing upon the ease with which they can be handled, and the service they will give. They are mostly graded from the softest to the hardest with numbers indicating their relative melting point. Thus a No. 1 grease is usually softer than a No. 2 grease, etc. A limesoap grease with a neutral reaction (which does not show any traces of an acid or an alkali) gives best results in service.

Clean—The grease should be free from dirt and grit and the percentage of water should be very low, as all of these would reduce the lubricating value and increase the heating of the bearing.

Melting Point—To insure its being retained in the bearing, the grease should have a melting point of 10 to 15 degrees C. above the normal operating temperature. If too hard, it will not flow readily and will increase bearing losses. On the other hand if the melting point is too low, it will not be retained in the bearing.

*This subject was discussed in a previous R. O. D. Feb. '18.

Cost—The same consideration referred to in connection with oil also applies to grease. In general, don't be misled by a highly colored or scented product with a fancy name and a correspondingly high price.

WASTE

Grades—Waste or packing is commonly made up of wool threads alone, or wool and cotton threads mixed with a resilient mineral or fibre, such as asbestos, cocoa fibre, moss, etc.

Dirt and Moisture—Dirty particles are liable to be carried by the oil up to the bearing and work into the oil film. All waste contains some moisture, but if too much is present, you pay for water instead of waste.

Elastic—Unless the waste is springy and elastic it will fall away from the bearing window, and thus cut off the supply of oil being fed to the journal. To secure this, it must be of the right grade of material, such as long wool threads or a mixture of wool threads, cotton threads, and a fibrous material. By proper machining, the material is intimately mixed and formed into a fleece with the threads all running in one direction.

Quality—Wool waste is commonly considered the best material as it is springy and elastic after being soaked in oil, and readily parts with the oil to the journal. However, its absorption property and wick action is not quite so good as that of cotton threads. Cotton threads are not springy, but absorb more oil than wool and have a better wick action. Some manufacturers consider a mixture of wool and cotton threads to give best results in service. A good packing should have the power of holding the correct quantity of oil evenly distributed through the threads of the waste, which should also be able to carry the oil by wick action against the force of gravity, if necessary, to the threads in contact with the journal.

Long Thread Wool — Shorter Thread Wool — Short Thread Cotton

Long Fibres are preferable as they carry the oil from the oil well to the bearing windows more satisfactorily than short strands, thus insuring a steady supply of oil. This is made possible by the wick action of the material when in a long continuous thread.

Special Preparations to make the waste springy and elastic are made up and used with fairly good results. They consist of various grades of wool and cotton thread mixed with horse hair or asbestos. Another brand is made by binding the waste in small bundles using a thin brass wire.

SUMMARY

1—Trade with reliable and experienced dealers

2—In considering first cost, do not lose sight of final results. A few hot bearings may wipe out all initial first cost savings.

3—Lubricants that have given good results in service need no further recommendations.

4—Neglect is frequently responsible for troubles charged up against oil, grease, and waste.

5—Proper facilities for handling and storage should be provided.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest, although information concerning specific designs of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1570—ARRANGEMENT OF BUS BARS—Why are the busses on a two-phase, four-wire switchboard nearly always installed A-1, B-1, A-2, B-2, rather than A-1, A-2, B-1, B-2? Is it to separate opposite polarities as much as possible or to better neutralize mutual induction? At first thought one would suppose induction effects would be better neutralized by installing A-1, A-2, B-1, B-2. R.D. (OHIO)

The induction of each phase is greater when the busses are arranged A-1, B-1, A-2, B-2 than when arranged A-1, A-2, B-1, B-2. The probable reason for originally installing the busses A-1, B-1, A-2, B-2 was to provide a simple method of opening or closing both phases simultaneously in case of short-circuits, or when synchronizing. This can be accomplished by connecting busses A-1 and B-1 to one double-pole switch and A-2 and B-2 to another.

C.M.L.

1571—CONVERTER OPERATION—To provide temporarily for charging large storage batteries it is proposed to use one 300 kw, 600 volt, three-phase, and one 500 kw, 600 volt, six-phase diametrical, compound rotary converter, connection diagrams of which are shown in Figs. (a) and (b). The transformers for the 300 kw set are three 110 kw, single-phase units, connected delta-delta, with inside delta taps on the secondaries for a starting voltage of 185 volts and a running voltage of 370 volts; the transformers for the 500 kw set are three 185 kw single-phase units connected as shown in Fig. (b), with starting voltages of 143 and 286 volts, and a running voltage of 430 volts. As 600 volts direct-current is higher than is desired, it is proposed to run the smaller set on the starting voltage of 185, giving approximately 300 volts direct-current, and the larger set on the second starting voltage of 286, giving approximately 400 volts direct-current; no changes are to be made in the wiring of the smaller set; on the larger set the reactive coils will be connected to the middle points of the left D.P.D.T. switch of Fig. (b), in order to have them in circuit when running on the starting point. The direct-current voltage will be further reduced as necessary by water rheostats, and the machines will carry their loads separately. Your opinion is requested as to this scheme and particularly as to the following:—(a) Will it be possible to obtain the full current ratings of the machines, 500 and 833 amperes, under the conditions outlined? (b) Will the change of location of reactive coils on the 500 kw set affect the starting of the set? (c) Why are the reactive coils located differently on the two sets? (d) What will be the probable effect on the power-factor of the machines if operated as outlined? (e) In case it is found possible to reconnect the secondaries of the transformers for the 500 kw set so as to obtain a single voltage of 215 volts, giving approximately 300 volts direct-current, which would be preferable? Would this be an excessively high voltage for starting a machine of this size?

L.F.W. (CAL.)

(a) It will be possible to obtain the full current ratings of the two machines operating at reduced voltages only on the basis of their being commutating-pole types. If they are non-commutating-pole, for given commutation characteristics, the output in amperes should be reduced approximately in proportion to the reduction of voltage. (b) If each machine is operating from its own bank of transformers, and is not in parallel on the direct-current side with any other apparatus, we would recommend omitting the reactance coils, altogether, on both machines, for storage battery service. (c) Figs. (a) and (b) indicate that the reactance coils are in the running leads on both the 300 and 500 kw units at the present time. (d) If rheostats have sufficient margin, the two machines should operate at 100 percent power-factor on the reduced voltages by adjusting the excitation. (e) The principle objection to rearranging the windings of the transformer for the 500 kw unit to give 300 volts direct-current would be the excessive k.v.a. taken from the alternating-current supply line when attempting to start on this high voltage (215) directly. We are assuming that the transformer taps and leads are of same current-carrying capacity as the full voltage leads.

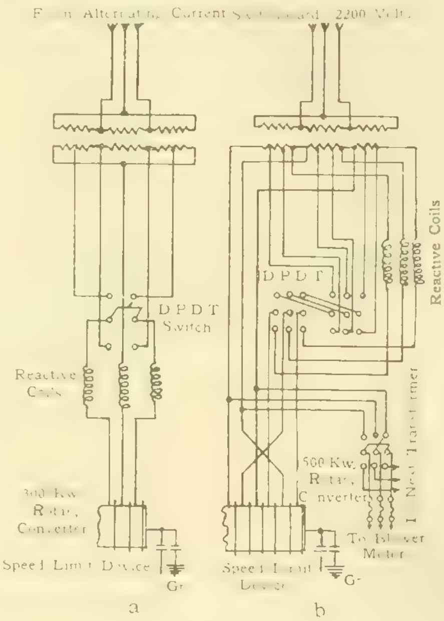


FIG. 1571(a) and (b)

R.H.N.

1572—CONDENSER FORMULA—Fig. (a) shows a source of direct-current at 110 volts, a bank of lamps and a signaling key. The circuit is practically non-inductive and a condenser placed across the contact of the key very materially reduces the spark at the points of the signaling key. With one single 25-watt tungsten lamp, the effect of the condenser, one microfarad capacity, is not noticeable. When, however, six or eight such lamps are in parallel a vicious spark was obtained without the condenser, and almost none at all when the condenser was connected. While it is true that with only one lamp the spark was not troublesome, yet it would be desirable to eliminate it still further, and the question is:—Should the condenser be of greater or less than one microfarad capacity to bring about this result? The frequency with which the key is operated is very slow, not faster than one stroke per second. If the lamps were replaced by a relay whose resistance and self-induction are known, can you give me a formula for calculating the capacity of the condenser, on the assumption that the key is opened once an hour by a clock mechanism. The electro-motive force employed is a battery whose voltage and internal resistance are given. This problem comes up every now and then in connection with the contacts in transmitting clocks, where a contact is opened once an hour, for instance, and it is necessary to calculate the capacity of the condenser to reduce the spark at the break. I have submitted this problem to other magazines and they always suggest the formula which shows the relation between capacity and self-induction to produce resonance, which formula always involves the frequency, but I cannot see how the frequency has much to do with this problem where we have but one break to consider, which occurs once an hour.

W.L.B. (N.Y.)

A very large condenser is needed to quench the arcing; for perfect suppression, if the circuit be entirely non-inductive, infinite capacity would be required. If, however, a small inductance, say, ten millihenrys, is inserted in series with the lamps, the arc should be almost perfectly extinguished by placing a one microfarad condenser across the contacts. There is about the same arc with six lamps in parallel as with only one; the quenching, however, is more noticeable with six lamps. In the case illustrated by Fig. (b), calculate the current I through the coil with the contacts closed. This value will be $E \div R$, where E is the open circuit or battery voltage and R is the total resistance in circuit, including the internal resistance of the battery. The energy in the inductance is then $0.5\ LI^2$ watt-seconds, where L is the self-induction of the

coil expressed in henrys. The energy absorbed by the condenser is 0.5 CE^2 watt-seconds, where C is the capacity of the condenser in farads and E expressed in volts is the maximum to which the potential difference across the contacts will rise when they are opened. If 0.5 LI^2 is made equal to 0.5 CE^2 there will be no arc, unless E is large enough to jump across the contacts. In your case with the values

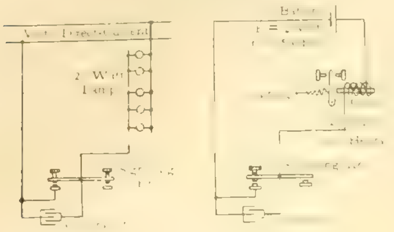


FIG. 1572(a) and (b)

given, if C is one microfarad, E will be about 10 volts, which should give quite satisfactory results. The quenching in such a circuit will be the most effective if R is less than the square root of $4L \div C$, as in this case the current through the condenser will oscillate and the arc will be suppressed when the condenser current passes through a maximum value, usually at its second or third peak.

1573—REWINDING INDUCTION MOTORS—Suppose one or more coils burn out in one phase of an induction motor would it be practicable to cut out the burnt coils and insert external resistance in the form of resistance wire, to keep from heating the rest of the winding? L.J.H. (OHIO)

One coil or sometimes several are cut out of a winding, and the motor operated in an emergency until proper repairs can be made. In general this is bad practice, because it throws a proportionate increase in voltage on all the remaining coils. This would not be taken care of by an outside resistance, as suggested. A coil offers not only its ohmic resistance to the flow of current, but it oposes also the counter e.m.f. generated in it by the rotating field. This factor could not be compensated by an external resistance, as suggested. In addition, there is a disturbance resulting to the magnetic field, due to the removal of a coil which cannot be balanced by any means outside the motor. To set up the field requires a magnetic motive force, which is measured by ampere-turns, and is the product of the amperes flowing, multiplied by the number of turns in the winding. If the number of turns is arbitrarily decreased as in cutting out a coil, this cannot be compensated for by anything outside the motor, and the motor attempts to make up for the decrease in turns by an increase in magnetizing current. However, this is only a partial compensation, since the dead coil affects the local distribution of the ampere-turns. In general, any motor will operate for a while with one or two coils cut out, but it is better practice to replace the damaged coils with new coils at the earliest opportunity, as the general performance of the motor is better under normal conditions.

A.M.D.

1574—DIRECT CURRENT MOTOR—I have a four-pole direct-current generator and one of the fields burnt out. Can I connect to the next field, and run the machine, the magnetic circuit traveling from the other fields through the frame, and out the pole face where coil is burnt out, and taken off? Could the above be run temporarily until coil was repaired?

E.M.D. (WASH.)

The results of connecting across one shunt field coil in a four pole machine will vary to a certain extent with the way the machine is designed. One result will be that the three remaining shunt field coils will run hotter since there will be about 1.8 as much heat generated in these coils. In a machine having a wave or series wound armature the machine ought to operate until the coil could be repaired; the only change being a little higher speed in a motor, or a lower voltage if a generator. However, if the machine be lap or parallel wound, and not protected by equalizer connections, the armature would also be liable to run hot on account of the circulating currents caused by the unbalanced field flux. Since most machines are either wave wound or, if lap wound, protected by equalizer connections, a machine will probably operate while one shunt coil is being repaired, but with a higher temperature in the remaining field coils. The limit in temperature which the cotton covering on field coil wire will stand is about 105 degrees. If operated at or above this temperature for any length of time the cotton covering will burn up.

R.M.C.

1575—CHANGING DIRECT-CURRENT MOTOR VOLTAGE—I have a ten horse-power, 230 volt, 1200 r.p.m. direct-current motor I would like to change to a 120 volt motor with same speed and horse-power. Am I correct in changing the armature connections from wave which it is at present to lap connection and paralleling the shunt and series fields, the machine being compound? Also I have a 500 volt series hoist motor with wave armature. Would this motor give the same horse-power on 250 volts if the armature was connected lap and two more brushholders added, also paralleling the fields? The ten horse-power motor mentioned above already has four brushholders but the series hoist motor has only two.

G.M.L. (UTAH)

You will be able to operate with half the voltage obtained with a wave winding by using a lap winding, provided you have a four-pole machine which you probably have from the rating you give. However, there are some restrictions to a change of this nature. In the first place, when you change from 230 to 120 volts you have about twice as much current to collect or you should use twice as many brushes per arm as the machine, built for 230 volts, is equipped with. If your commutator is not long enough for the addition of twice as many brushholders, you will be overworking the brushes if you try to get ten horse-power and you will probably have commutator trouble. There is another serious objection to this change. Your ten horse-power motor probably has four poles and thus, with a wave winding, must have an odd number of commutator bars, the armature also probably has an odd number of slots. This condition will make the winding unsymmetrical as a lap winding and thus will lead to circulating currents with consequent heating and commutator trouble. The better plan will be to buy a 120 volt armature from the manufacturer or, if the armature has an even number of turns per coil, to connect the turns in two groups in parallel. It will also be a good plan to connect your fields in parallel so that the two north pole windings will be in the same circuit and not a north and a south pole. The same system of reconnection will apply to the 500 volt hoist motor which you mention, provided it is a four-pole machine.

R.M.C.

ENGINEERING NOTES

Aim—To connect theory and practice

Iron-Core Reactors

In an air core reactor, the voltage across the terminals of the reactor varies directly with the value of current passing through the winding. This is because air having a constant permeability forms the magnetic circuit. In an iron core reactor the voltage varies directly, with the value of current up to a certain limit, (saturation of the iron) beyond which the voltage will vary at a less rate than the current.

In general, if the voltage of a reactor is not required to vary directly with the current at values materially above its full-load current rating, the iron core reactor will be cheaper. If the voltage is required to vary directly with current up to current values which will heat the copper to the limit in a relatively short time, an air core reactor is desirable; as, if an iron core were used, it would be necessary to work the iron at a very low flux density at full load and no material gain in flux density is possible over the air core type. The iron core reactor has the advantage, however, that it is possible to confine its magnetic field within the reactor itself, whereas the air core reactor sets up a strong field outside of its mechanical limits.

An iron core reactor consists of a winding of several turns on a magnetic circuit having a high reluctance to the path of the flux. The impedance of the reactor will be inversely proportional to the magnetic reluctance and directly proportional to the frequency and to the square of the number of turns, assuming that the resistance of the winding is negligible.

The current which will flow in the circuit with a given voltage drop across the terminals of the reactor may be considered as the exciting current of the reactors. As an example, an ordinary transformer, operating with the secondary circuit open may be considered as a reactor. In this case the voltage across the terminals builds up very rapidly for small values of current until saturation of the iron circuit is reached, after which voltage will build up at a very slow rate with increase in current. In fact a curve plotted between voltage and current is the typical saturation curve of iron. As the exciting current in a transformer is only about ten percent of the full load current, the iron will be saturated at a current of about ten percent of the value which the winding will carry. This then means that there are more ampere-turns available in this winding than are required to magnetize the iron, hence the iron becomes saturated when full-load current is passed through this winding.

In an iron-core reactor, the current which will pass through the windings, with a given voltage drop across the terminals of the reactor will vary, within certain limits, directly with the reluctance of the magnetic circuit, or conversely, the drop in voltage across the reactor with a given current will vary, within limits, inversely as the reluctance. Since the reluctance is proportional to the length of the magnetic circuit divided by the product of the areas of cross-section and permeability of the iron, it can be increased by increasing the length of the circuit or decreasing the cross-section or permeability. Increasing the length of the magnetic circuit is not a practical procedure in that the weight would not only be too great but the cost would be prohibitive. If the area of cross-section is diminished, since the voltage applied and number of turns are assumed as constant, the density of the flux is obviously increased. Saturation of the magnetic circuit will be reached at about 20 000 to 25 000 gausses, depending on the grade of steel used and, after passing the knee of the saturation curve, a much greater increase in exciting current is required to produce a given voltage drop.

Since air has a permeability very low compared with iron, if a small air-gap be placed in the magnetic circuit, most of the ampere-turns available in the coil are required to force the flux across this small air-gap. Since the permeability of this air-gap is constant (being that of air) the reactor will act the same as an air core reactor up to the point at which the flux becomes great enough to saturate the iron circuit. By making the air-gap of a proper value for the ampere-turns and magnetic circuit involved, the iron will not become saturated until a predetermined value of current is reached, this value usually being somewhat above the full-load rating of the reactor. As a matter of fact, due to the large number of ampere-turns used up in the air-gap, the flux density can be run very high before the voltage obtained deviates materially from the straight line characteristic of an air core reactor.

The limits of this variation are the saturation of the iron and the fringing of the air-gap. It is found that as the length of the air-gap is increased, the flux tends to fringe out in crossing, giving an effective area greater than the cross-section of the core and therefore a less dense flux in the air-gap. With small air-gaps from one-sixty-fourth to three-sixteenth or one quarter inch, this fringing is not appreciable and the variation of current and voltage will be proportional, as described above, but with longer gaps this fringing becomes quite marked and the change of voltage is not quite proportional to the change in the air-gap.

An expression for the impedance voltage of the reactor is given in the following formula:—

$$E = \frac{0.201 \times N^2 \times I \times f \times A}{l_g \times 10^6}$$

Where N = number of turns
I = amperes flowing in winding
f = frequency in cycles.
A = effective area of air gap in sq. inches.
l_g = length of air gap in inches.

The effective area of the air gap is closely approximated by $A = (x + l_g)\ (y + l_g)$ where x and y are the dimensions of the cross-section of the iron.

W. R. Woodward

Sealing Leads on Auto-Starters

The following method of insulating leads on auto-starters will prevent siphoning of oil:

a—Remove insulation from each lead just above the highest oil level for a distance of two inches.

b—Sweat the strands of the cable thoroughly together so as to close up all spaces between the conductors for a distance of one inch.

c—Insulate the lead with treated cloth tape, wrapping the tape tightly around the conductor and brushing each layer with insulating varnish while wrapping.

d—Extend the wrapping to tape with three overlapping layers at least one inch on the insulation at each end of the bare section.

THE ELECTRIC JOURNAL

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Armature Reaction

No science has done more to revolutionize our mode of life and fashion of thought than electrical engineering. The children of today are incredulous and amused that, as children, their parents enjoyed no telephones, trolley cars, electric lights nor a legion of devices which advance their Today so far beyond our Yesterday.

No science is more replete than electrical engineering with terms unfamiliar to the lay ear. And yet words the most mysterious are often of very practical importance to "the man in the street"—though he knows it not. He accepts the fact with no thought of cause. How many ex-rheumatics give any thought to the dental Rœntgenography which aided in their relief? How many automoblists today thank Faraday for his researches ninety odd years ago in electromagnetic induction? But for "phantom circuits", how would the price of telegrams and telephone messages increase, under the burden of the copper alone that the companies would have to buy?

In all our electrical vocabulary, there are few expressions of more work-a-day importance to the operating engineer than "armature reaction." How often does he stop to think that only the mastery of its significance in machine design made possible the old close-regulating alternator, so necessary to the establishment and growth of constant potential distribution systems—the very back-bone of our central station practice? Or that, with the more widely regulating generators permissible after the advent of the automatic voltage regulator, this same armature reaction is intimate with the protection of machines from injury, both electrical and mechanical, upon short-circuit?

Every operator is treading on the heels of armature reaction, when he parallels his generators to divide the load according to his needs and their safety. Armature reaction in the synchronous condenser makes normal the behavior of the generator disturbed by the effect of lagging power-factor on its own brand of armature reaction. When the station engineer switches his generator onto a long, unloaded transmission line, and his voltage begins to run away, does he recognize the handiwork of armature reaction? When he despairs of getting accurate results from input-output efficiency tests on many kinds of machinery, does he know whether armature reaction plays any part in his discomfiture?

Not to multiply cases, this expression is pregnant with practical interest for the electrical man, who too often is either stranger to the term or has at best but a bowing acquaintance. Mr. F. D. Newbury's article on the subject in this issue of the JOURNAL presents the phenomenon with such masterly clearness that the thoughtful reader may well feel that the mystery of its identity has been solved, and be correspondingly encouraged toward more intimate knowledge of its effect upon The Days Work.

NICHOLAS STAHL.

Automatic Substations

Economy and man-saving, in particular, are being emphasized on every hand. The automatic substation, a man saving device, is therefore particularly timely. The scheme is logical;—the types and kind of apparatus employed have had their reliability demonstrated in other more or less similar fields where the duty has been even more exacting and where failure would be fully as objectionable. A certain hesitancy is perhaps natural, and caution is advisable when new methods or more or less untried methods of operation are proposed. Only nine years ago outdoor substations were proposed as a desirable means of reducing substation costs. There was strong opposition when they were proposed as desirable, and great fears were expressed concerning their ability to render continuous service. Today they are very common and indications point to even still more general adoption.

The multiple-unit automatic control of electric cars, involving thorough dependability and continued reliability, is an excellent illustration of accomplishment along these same lines, where almost brain-like response and susceptibility is demanded of the control equipment. There have been, of course, individual problems and difficulties with some applications. This is to be expected but, as a whole, the problems have been met and solved.

The automatic substation, as described by Mr. Wensley in this issue, gives every promise of rapidly coming into common use and becoming an important factor in railway electrification. The natural caution now exhibited will soon give way to confidence based on the experience which is rapidly being acquired from satisfactory service. Confidence is further justified in that the individual apparatus employed is very largely, if not entirely, of established standard design, this service being merely a new application. Hence, the advent of the automatic substation is particularly auspicious and its early general adoption may be confidently expected.

K. C. RANDALL

Armature Reaction of Polyphase Alternators

F. D. Newbury

If an alternator is carrying load, and the exciting current is not changed, any change in the amount or in the power-factor of the load current will cause the delivered voltage to change; or if, as is usually the case, the voltage is held at a constant value, changes in load will require a change in the exciting current. As is well-known, an increase in the lagging component of the load current causes a drop in voltage or requires an increase in exciting current to maintain constant voltage; and a decrease in the lagging component or an increase in the leading component causes an increase in voltage, or requires a reduction in the exciting current to maintain constant voltage. Since lagging currents and power-factors are much more common in practical work than leading currents and power-factors, the former condition will be assumed, except when a leading current is expressly mentioned.

Drop in terminal voltage due to an increase in load is caused by three factors: the resistance of the armature winding, the reactance of the armature winding, and the armature demagnetization or reaction. It is convenient to group the first two and consider them as a single voltage factor, resulting in a voltage drop due to impedance. The third factor—the armature reaction—is purely a magnetic flux phenomenon. Of these factors, the armature reaction is the more important. If a turbogenerator, for example, has a total voltage drop of 40 percent when rated load at 80 percent lagging power-factor is applied (the excitation being that required to produce rated voltage at rated load), three-fourths of this drop may easily be due to the armature reaction.

Current flowing in a circuit of whatever form sets up a magnetic field that reacts on any other adjacent magnetic field. Thus, in an alternator the load current flowing in the armature winding sets up a magnetic field that reacts on and modifies the form and strength of the main exciting field. The most direct method of studying this armature reaction is to determine graphically the effect of the armature field on the main exciting field and the resultant effect on the generated voltage.

To reduce the polyphase armature to its simplest form, consider a two-pole alternator having a two-phase armature winding, Fig. 1. Throughout this discussion, the rotating field structure will be assumed. This is contrary to usual practice and requires the use of a direction of motion contrary to the actual direction of rotation, when determining the direction of e.m.f. generated in the stationary armature conductors.

With the rotor in the position shown, the voltage generated in the conductors of phase A has its maximum value and the voltage generated in the conductors of phase B is zero. The direction of voltage in the conductors of phase A is away from the reader, (as indicated by the crosses) in the conductors opposite the north pole and is toward the reader, (as indicated by the dots) in the conductors opposite the south pole. These voltage directions are determined by the directions of flux and relative conductor rotation assumed. If current is flowing in the armature winding due to these voltages, and the current is in phase with the generated voltage (or with the terminal voltage, assuming no armature drop) the current in phase A will have its maximum value in the same direction as the voltage and the current in phase B, at the assumed moment, will be zero. The current in phase A will set up a magnetic field as shown in Fig. 2. This armature field—or armature reaction—due to current in phase with the no-load voltage is seen to have a space position at right angles to the main exciting field and a direction such that the north pole of the armature field is in advance of the north pole of the main exciting field. (It is in advance from the standpoint of the relative direction of rotation of the armature conductors, although it is behind from

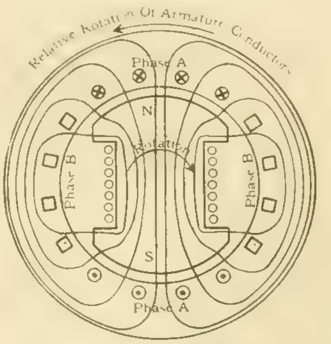


FIG. 1—SCHEMATIC DIAGRAM OF ELEMENTAL TWO-PHASE, TWO-POLE, ALTERNATOR

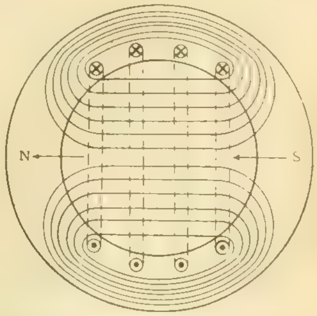
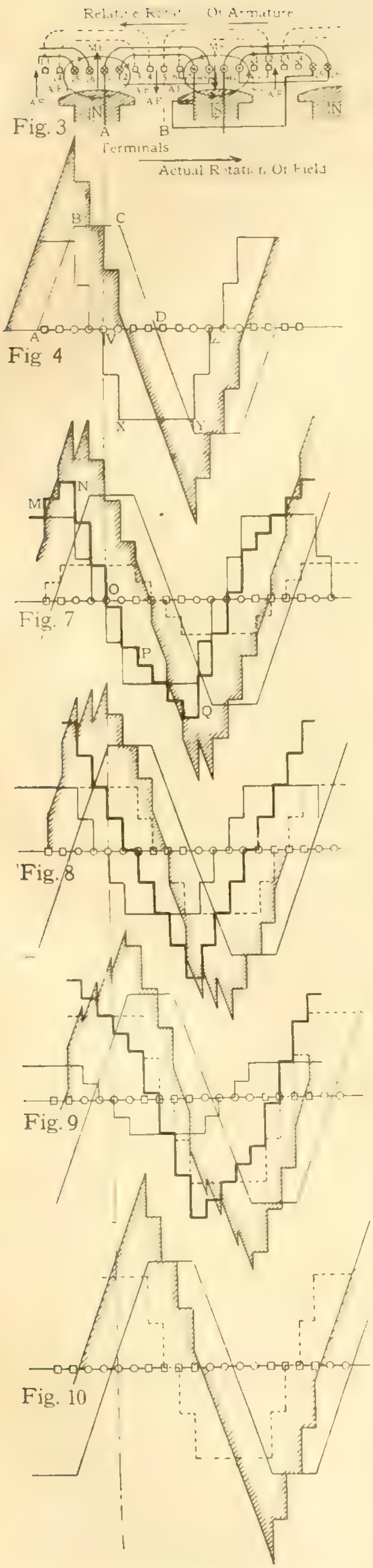


FIG. 2—FLUX INDUCED BY CURRENT IN ARMATURE CONDUCTORS OF PHASE A

the standpoint of the actual direction of rotation of the rotating field). These relations are more easily seen in Fig. 3, which is a developed picture of the two field poles, and the armature winding of Fig. 1. The directions of the main flux MF and the armature flux AF are indicated. The direction of the armature flux is determined by what may be called the direction of the winding, as well as by the direction of current in the active or slot-portion of the conductors. Thus, in Fig. 3, the current in the slot-portions of the conductors *7-8-9-10* is the same, *i. e.,* toward the reader as indicated by the dots; but the flux due to the current in conductors *7-8* is in the direction of the flux from the south main pole—or below the zero axis in Fig. 4, while the flux due to current in conductors *9-10* is in the direction of the flux from the north main pole—or above the zero axis in Fig. 4. This is because conductors *7-8* are connected in the winding in a clockwise direction, while conductors *9-10* are connected in a counterclockwise direction. In Fig. 4 the combination of main flux and armature flux has been carried out graphically. The form of the main field has been assumed to have the



FIGS. 3 TO 10—SUCCESSIVE FLUX DIAGRAMS

Showing the rotation of the armature field.

trapezoidal shape *A B C D*. While this is somewhat different from the field form of a salient pole generator, it approximates that of a turbo-generator, having the usual cylindrical rotor. It is sufficiently close to the actual case for any generator for the present purpose.

Considering a single group of two coils, the armature field is assumed to have uniform maximum strength between the two inside conductors or inside turn, and to attain this maximum strength by a number of steps equal to the number of turns. This field form is represented by the stepped figure *V X Y Z*, Fig. 4. Another example of armature field is shown in Fig. 5.

These curves of armature flux are, strictly speaking, curves of magnetizing force or ampere-turns. The true flux curves are modified by the shape of the magnetic circuit. In a turbo generator having a cylindrical rotor and a uniform length of air-gap, the curves of magnetizing force and flux have the same shape; in a salient pole generator, the flux density due to armature ampere turns in that part of the air-gap between the rotor poles will be considerably reduced on account of the longer air path. In the present discussion, the field due to armature reaction will be assumed to have the same shape as the space distribution of ampere-turns. The resultant field is obtained by adding or subtracting, as the case may be, the ordinates of the main exciting field and of the armature field. In Fig. 4 the resultant field has increased in strength at the trailing pole tips (referred to the actual direction of rotation of the revolving field) and has decreased in strength at the leading pole tips. The effect of the armature reaction has also been to shift the resultant field backward with reference to the motion of the rotor. This shifting of the resultant field may be pictured as a retardation of the exciting field as load comes on. It results in a delay in the time of maximum voltage—or, in other words, in the full-load voltage lagging behind the no load voltage wave, (using the main field flux as the fixed reference for phase).

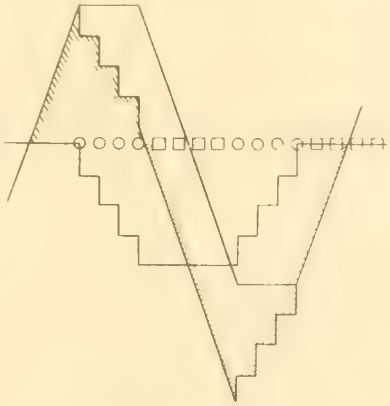


FIG. 5—FLUX DIAGRAM OF CONSEQUENT POLE ARMATURE WINDING

In Figs. 3 and 4 each phase of the armature winding is so connected as to form two groups of two coils each instead of one group of four coils, as might appear from Fig. 2 to be the obvious arrangement. If the latter arrangement is used—and such an arrangement of the winding would generate the same no-load voltage as the arrangement in Fig. 3—the armature reaction would be doubled and would be unsymmetrical with respect to the main field. This is illustrated in the combined flux diagram of Fig. 5. For obvious reasons, this is not a desirable winding, and is seldom, if ever, used in practice.

Figs. 1 to 4 show the main field, armature reaction, and resultant field at only one instant; at the time when the voltage and current in phase *A* have their maximum values and the voltage and current in phase *B* are passing through zero. During operation, the position of the rotor, and the values of voltage and current are continuously changing. When the rotor has turned 45 degrees, for example, the voltage and current in phase *A* have decreased to 0.7 of their maximum values and the voltage and current in phase *B* have increased from zero to 0.7 of their ultimate maximum and in the

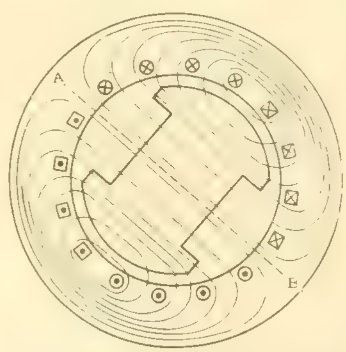


FIG. 6—ARMATURE FIELD WITH PHASES *A* AND *B* EQUALLY EXCITED

same direction as the voltage and current in phase *A*.* At this instant of time, the armature reaction is due to the currents in both phases. From the direction of currents in the two phases, as indicated by the dots and crosses in Fig. 6 it is obvious that the two phases are equivalent, in magnetizing force, to a single coil wound about the axis *AB*. The general direction of the resultant field is indicated roughly by the lines of force drawn in Fig. 6.

These changes can be more exactly investigated by plotting a series of flux diagrams, such as Fig. 4, for a number of times at equal intervals. This has been done in Figs. 7, 8, 9 and 10, showing the instantaneous values and phase positions of main flux, armature flux and resultant flux for positions of the rotor 22.5 degrees apart. (1-16 revolution in the two-pole generator). Since there are 16 armature slots, each position is one armature slot in advance of the previous position illustrated. Thus in Fig. 7 the position of the main exciting field (determined directly by the position of the rotor) is 22.5 degrees or one armature slot in advance of the position in Fig. 4. During this time the current in phase *A* has decreased in value to 92 percent of its maximum value in Fig. 4 (sine of 67.5 degrees) and the current in phase *B* has increased from zero to 38 percent of the maximum value (sine of 22.5 degrees) and in the same direction as the direction of current in phase *A*, as already explained. The armature reaction at this instant is due to current in both phases, as shown by the resultant curve *M N O P Q* in Fig. 7. Each of the successive figures (Figs. 8-10, inclusive) represents instantaneous conditions at successive intervals of time, corresponding to rotation of 22.5 degrees. The five figures cover conditions during one-quarter cycle; conditions during successive quarter-cycles will be the same. It is seen that in a two-phase armature there are two single-phase armature fields spaced 90 degrees apart. When one field is at maximum strength, the other disappears, and when the former disappears, the latter field reaches its maximum strength.

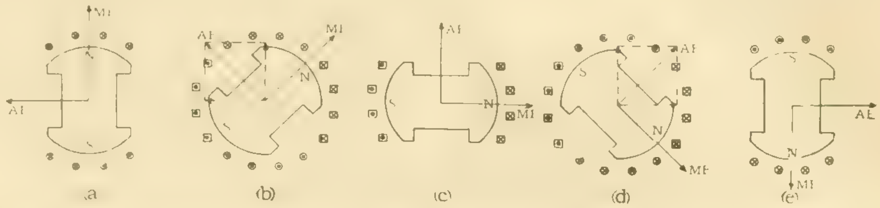


FIG. 11—VECTOR REPRESENTATION OF ARMATURE FIELD IN A TWO-PHASE ALTERNATOR

While the shape of the polyphase armature reaction curve varies considerably at different instants, the total flux (proportional to the area enclosed by the resultant curve) will be found to be practically constant. Further, the space position of the resultant armature reaction curve changes synchronously with the position of the main exciting field—that is, with the position of the rotor. In each position illustrated, the zero points in the resultant armature reaction curve fall directly under the maximum points in the main exciting flux curve; the armature flux rotates with the rotating exciting field, and is at all times 90 degrees behind it. This is merely a demonstration of the familiar fact that a polyphase winding produces a rotating field of constant value. This fact may be also shown, and perhaps in a simpler way, by means of vectors representing the magnitude and space position of the two single-phase fields. Fig. 11 is such a picture. Fig. 11 (a) shows the same conditions as Figs. 1 and 4. The current is a maximum in phase *A* and is passing through zero in phase *B*. The armature flux *AF* is due solely to phase *A*. Fig. 11 (b) shows the conditions after the rotor has turned 45 degrees. The current in phase *A* has decreased to 0.7 of its maximum value and the current in phase *B* has increased to 0.7 of its maximum value. Thus the armature field *AF* is the resultant of two equal component fields. The resultant armature field has thus been shifted 45 degrees, so that it still bears the 90 degree relation to the no-load exciting field *MF*, and it has the same maximum value as in Fig. 11 (a). Fig. 11 (c) shows conditions after another 45 degree turn of the rotating field. At this instant, the current in phase *B* has reached its maximum and the current in phase *A* has dropped to zero. The armature field is due to current in phase *B* alone. Fig. 11 (d) is identical with Fig. 11 (b), except that the current in phase *A* is now reversed (since the conductors previously under the influence of the *N* pole are now under the influence of the *S* pole) so that the flux is in the reversed direction.

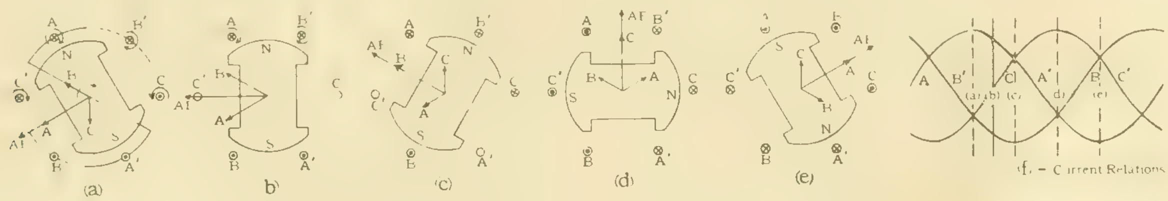


FIG. 12—VECTOR REPRESENTATION OF ROTATING ARMATURE FIELD IN A THREE-PHASE ALTERNATOR

*It is immaterial whether it is assumed that the current in phase *B* increased in the same direction or in the opposite direction, providing the space location of phase *B* winding is properly taken for the assumption made. For example, the current in phase *B* increases in the same direction as the current in phase *A*, if the terminal coil of phase *B* is ahead of the corresponding terminal coil of phase *A*, and, conversely, the current in phase *B* increases in the opposite direction if the terminal coil of phase *B* is behind that of phase *A* as connected in the winding. The result is the same in Fig. 7 whether the armature reaction for phase *B* is plotted below the zero line with the terminal coil in slot *5* as shown (see Fig. 3) or above the zero line, the terminal coil being in slot *13*. This difference in relative location of the *B* terminal results merely in a difference of phase rotation.

Throughout this half cycle, the maximum value of the armature field remains constant, and its space position changes synchronously with the rotating field.

A similar analysis for a three phase winding is illustrated in Fig. 12 and leads to the same result. The reaction of any symmetrical polyphase winding is constant in value and rotates in the same direction and with the same speed as the alternator field. In using vectors to represent the two component armature fields, the assumption is made that the flux curves have a sine shape. If in Figs. 4 to 10 the armature flux forms had been sine curves, the resultant flux in these figures would also have had the sine form, and the maximum values, as well as the areas, would have been equal, and thus would have agreed with the results shown in Fig. 11. With the winding spacing necessarily used in generators, the armature flux never has a sine shape so that vectors do not lead to results correct in all respects.

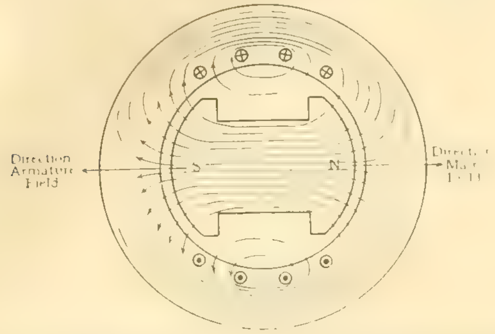


FIG. 13—RELATIVE POSITIONS OF MAIN AND ARMATURE FIELDS
With armature currents lagging 90 degrees.

The effect of power-factor on armature reaction can be shown by a series of flux diagrams similar to Figs. 4-10, but based on the assumption of currents lagging 90 degrees behind the no-load voltage. It has been shown that the armature reaction with current in phase with the voltage amounts to a rotating field of constant value, having a space position at right angles to the main exciting flux. The effect of lagging current is to retard the position of this rotating flux with respect to the position of the generator rotor. For example, in Figs. 1 and 2, when the rotor is in the position shown, the voltage is a maximum, but under the present assumption, the current is passing through zero. The current and its field, as illustrated in Fig. 2, will not reach its maximum value until a quarter cycle later, when the rotor will have turned 90 degrees, as shown in Fig. 13. The result of this 90 degree lag in current and flux is to bring the main field and armature field directly in line and in opposite directions. Thus the rotating armature field directly opposes the main exciting field, and causes a large drop in generated voltage, or requires a large increase in field current to maintain the voltage.

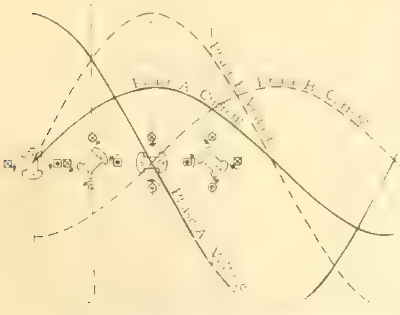
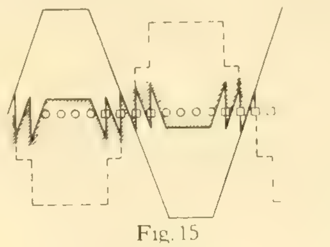
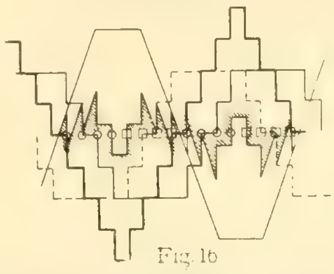


FIG. 14—DIAGRAM OF PHASE RELATIONS
With 90 degrees current lag.

To investigate the conditions at zero lagging power-factor more fully, assume that the voltage and current conditions are as shown in Fig. 14. The terminal coil of phase *B* is ahead of the corresponding coil of phase *A*, so that the voltage and current in phase *B* lag behind those of phase *A*. Figs. 15 and 16 show the armature flux, main field flux and resultant flux for positions of the rotor 45 degrees apart. In Fig. 15 the armature reaction is due to current in phase *B* only, and is in such a direction as to oppose the main flux. Similarly, in Fig. 16 the resultant armature flux directly opposes the main flux. In the figures the resultant flux is very small, since the armature flux has been subtracted from the no-load value of the main flux. The conditions shown approximate those when a generator is operating with the armature short-circuited and with just sufficient field current to circulate full-load current in the armature. It will be observed that under these conditions, the resultant flux changes its shape materially and reverses several times during a cycle. This explains why in some generators the loss measured on short-circuit may be greater than the true load loss at normal voltage. When operating under normal lagging current and normal voltage, the same armature flux as shown is opposed by a main field of two or three times the strength of the no-load field.





FIGS. 15 AND 16—RESULTANT FLUX WITH 90 DEGREES CURRENT LAG
Fig. 15—Zero current in phase *A*.
Fig. 16— Equal currents in phases *A* and *B*.

A similar analysis would show that with current leading the no-load voltage by 90 degrees, the armature field directly assists the main exciting field. At intermediate power-factors, the space position of the resultant armature flux will vary between the 90 degree relation existing at 100 percent power-factor and the in-phase relation existing at zero power-factor. The armature reaction itself is not modified by a change in power-factor (except for the change in magnetic reluctance in a given path in a salient pole generator); the change in resultant exciting flux is due to the change in space relation of armature reaction and the exciting flux. The polyphase armature reaction is roughly equivalent to the flux of a single coil or winding for each pole of the alternator, excited by direct current, and which rotates synchronously with the rotating field. The space position of this hypothetical coil varies from the center line of one alternator pole to the center line of the adjacent pole, depending on the power-factor.

Industrial Controllers-XVI

Ore and Coal Bridges

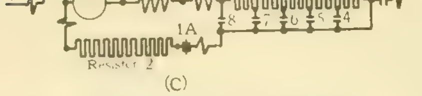
H. D. James

ORE bridges are used for the handling of ore and coal, principally on the Great Lakes. During the navigation period, ore is shipped from the Lake Superior region to the lake ports in the East, and coal is shipped back. The ore boat is a long vessel made up almost entirely of cargo space. The propelling machinery is usually at the rear, which leaves the body of the boat free for cargo. The ore is loaded into the boats at the Lake Superior ports from bins by means of chutes. When the boat reaches its eastern destination in the neighborhood of Cleveland or Buffalo, the ore is taken out of the boat and, either loaded in cars for transportation to the blast furnaces, or placed in stock piles. The coal is then loaded into the boat from cars by means of a car dumper and is taken out of the boat at the Lake Superior ports by means of an unloading bridge.

An ore or coal bridge, Fig. 1, consists of a structural steel span supported on two piers. These supports are mounted on tracks and moved by electric motors. On the bridge is a runway supporting a trolley, which is moved forward and back on the bridge by electric motors and carries the hoisting mechanism for raising or lowering the clam-shell bucket. Usually the operator rides in this trolley familiarly known as a "man trolley." The bridge is moved along the tracks until the clam-shell bucket is in position above the hatchway. The bucket is lowered into the boat and lifts the ore or coal up through the hatchway, carrying it back to bins or a stock pile. The bins are used for loading cars in the usual manner. During the summer, a surplus of ore is accumulated at the Great Lake stations in large piles known as "stock piles". At the time of unloading, the ore is graded, so that the burden in the clam-shell bucket may be dropped close to the dock or a considerable distance back, depending upon the location of that particular grade of ore.

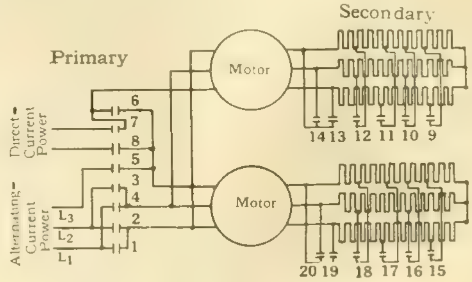
FIG. 1—ORE BRIDGE

Operated by direct-current motors and controllers. A pile of iron ore is shown under the bridge and blast furnaces at the right and in the back ground.*



Notches	1	2	3	4	5	6	
Hoist — Close Switches	1-3	4	5	6	7	8	
Lower Kick Off Close Switches	1A-2-3						Method 1
Lower Brake – Close Switches	1A-3	4	5	6	7	8	Method 1
Lower — Close Switches	1A-2-3	4	5	6	7	8	Method 2
Off Position — Close Switches	3A						

FIG. 2—CONNECTIONS OF DIRECT CURRENT MOTORS AND CONTROLLERS FOR HOIST INSTALLATIONS



Notches	1	2	3	4	5	6
Hoist- Close Switches	1-3-5-6	9-15	10-16	11-17	12-18	13-14-19-20
Lower-Close Switches	2-4-5-6	9-15	10-16	11-17	12-18	13-14-19-20
Brake- Close Switches	7-8	9-15	10-16	11-17	12-18	13-14-19-20

FIG. 3—CONNECTIONS FOR ALTERNATING CURRENT HOISTING

Used in installation shown in Fig. 7.

Special machines are frequently used for the pur-

*Bridge built by Hoover & Mason.

pose of unloading the ore from the boat. Where such machines are employed, the ore bridge is used for transferring the ore from the unloader proper to the stock pile or bins. Where the ore bridge is used for unload-

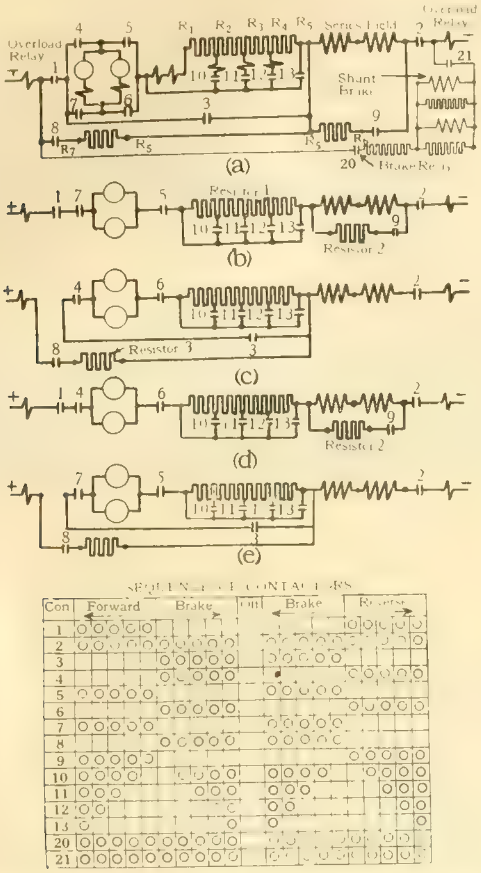


FIG. 4—CONNECTIONS OF MOTORS AND CONTROLLERS FOR TROLLEY APPLICATIONS

ing the boat, provision is sometimes made for twisting the bucket through 90 degrees to facilitate picking up the ore in the hold of the boat.

The application of motors and control to an ore or coal bridge divides itself into three distinct classes; *viz.*, hoist, trolley and bridge.

HOIST

The hoist is equipped with two drums, one drum handling the shell line and the other the closing line. The shell line is attached directly to the stirrup of the bucket, while the closing line is attached by levers in such a manner that pulling on the closing line causes the jaws of the clam-shell to come together and retain the load. In picking up a load, the bucket spades are in a vertical position, with the closing line slack. The bucket is then lowered into the ore or coal and the closing line pulled up. The tension on the closing line moves the two shells together, after which the hoisting may be done on both the closing and the shell lines. To discharge the burden, the load is held by the shell line and the closing line is slackened.

When only one hoisting motor is used, the two drums are controlled by clutches. Where two motors are used, one is connected to each drum, each motor having a separate controller and usually a separate master switch. By using two motors and adjusting the resistance, the proper tension can be kept on the closing and shell lines so that the bucket will not open until the operator changes the adjustment.

Direct-Current Motors are series wound and operated as standard series motors in the hoisting direction. In lowering, a kick-off notch is provided which connects the armature and field in parallel across the line. This causes the motor to operate as a shunt motor. After the bucket has started down, there is always sufficient weight to overhaul the hoisting mechanism so that the armature generates through the series field and provides dynamic braking. After this braking circuit has been once established, the speed of lowering can be controlled by changing the resistance in the dynamic brake circuit. The motor may or may not be disconnected from the line, depending upon which condition gives the most economical operation.

The schematic arrangement of such a control for a single motor is shown in Fig. 2. If two motors are used, two controllers are supplied, one for each motor. The switch marked *3A* in Fig. 2 (a) is closed only in the central or off position. This dynamic brake circuit does not include the magnet brake* coil; therefore, the friction shoes set and the motor is brought to rest.

The connections for hoisting are given in Fig. 2 (b). This is a straight rheostatic controller, the speed of hoisting being controlled by a cutting out of resistance in series with the armature and field.

The connections for lowering are given in Fig. 2 (c). On the first notch, the current comes in through switch *2* to a point between the armature and field. It

FIG. 5—ALTERNATING-CURRENT CONTROL PANEL

Designed for two motors and used in trolley applications. Double-pole switches are used throughout to insure that the direction and acceleration of the motors is maintained uniform.

passes through the field and brake magnet to the starting resistance and thence through switch *3* to the line. Another branch of current passes through the armature in the reverse direction and through a resistance to con-

*By "magnet brake" is meant a friction brake which is set by a heavy spring and released by a magnet.

tact *1-A* and thence to contact *3* and the line. This keeps the current flowing through the field in the same direction while it reverses the current through the armature, causing the motor to rotate in the opposite direction. After the motor starts, the load drives the motor as a generator, the circuit being through the field and resistance *1* to resistance *2* and thence through the armature, completing the circuit. When this condition is established, switch *2* may be opened. The motor then runs as a generator at its maximum speed. By successively closing switches *4* to *8* inclusive, the resistance of this circuit is decreased and the speed of lowering decreased. In order to stop, the controller is moved to the central position, closing switch *3-A*, in Fig. 2 (a), which sets the magnet brake and brings the hoist to rest.

Other methods of connecting the motor armature and field for lowering have been proposed, but they all follow the same essential arrangement, as shown in Fig. 2; namely, the motor is operated as a shunt generator for the kick-off or starting point and as a series generator for lowering. Sometimes a reverse current relay is placed in the armature circuit to disconnect the motor from the line automatically as soon as regeneration begins. If a heavy load is lowered frequently, it may be more economical to keep the motor connected to the line, so that power will be returned to the system. Usually, however, the bucket is lowered empty and hoisted with a load. It is then trolleyed over to the proper point and the load dropped without lowering the bucket, as this saves time.

FIG. 6—ORE BRIDGE

Equipped with direct-current motors and controllers, and having a 10 ton bucket. Two motors are used on the hoist and one on the trolley. A large pile of iron ore is shown in the foreground and the blast furnaces in the background.*

Alternating-Current Motors — Wound-secondary induction motors with external resistance have been in sucessful use for over eight years on bridges of this type. The control is shown diagramatically in Fig. 3. For operation under power, the control does not differ in any way from the standard reversing controller. The motor is connected to the line with all of the resistance in the secondary and this resistance is gradually short-circuited to bring the motor up to full speed. Dynamic braking is obtained by connecting the primaries of the motors in series to direct-current power, which is usually furnished by a motor-generator set. The resistance is inserted in the secondary. With the motor at full speed, the direct-current power provides a stationary field, which produces the same effect as when the motor is at rest and the alternating-current rotating field is provided. As the resistance is cut out of the secondary of the motor, it is gradually slowed down until it operates at a very slow speed with the secondary short-circuited. The controller illustrated in Fig. 3 can be arranged for the same number of power and brake

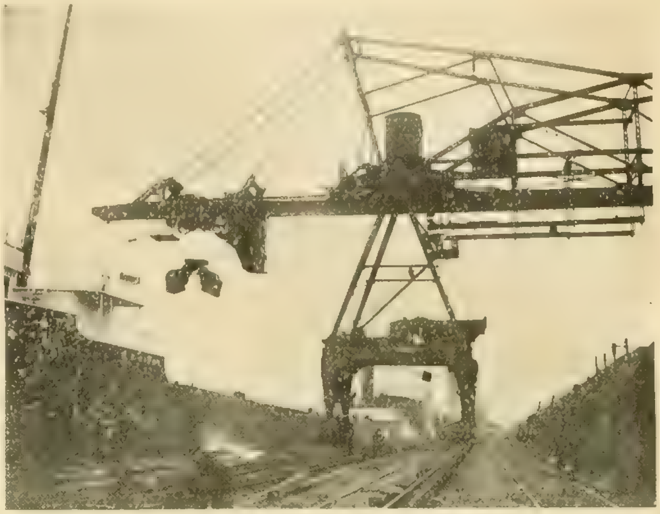


FIG. 7 ORE BRIDGE UNLOADING COAL FROM BOATS

Showing pier leg of bridge, bucket and man trolley. This bridge was the first one which used alternating-current motors for coal handling and is equipped for dynamic braking. The bucket has a five ton capacity and this installation has been in successful operation for over eight years.*

FIG. 8—ORE BRIDGE

Showing the 13 000 volt, high-tension transmission lines which are connected through sliding contacts directly to transformers mounted on the bridge, thus effecting a material saving in copper and insuring good voltage regulation at the motor. This is very important with alternating-current, as the torque of induction motors varies as the square of the voltage.*

*Bridge built by Heyl and Patterson.

notches on either side of the off position when used for trolley applications. It is simplified for hoisting by omitting the brake connections for the upward travel of the bucket and reducing the number of power notches for the downward travel. These are details of the master switch connections. Sometimes a magneto, or small direct-current generator, is driven by the motor shaft to operate a relay for disconnecting direct-current power from the motor fields and applying the brake when the speed has been reduced to a predetermined value. This magneto may also be used for setting the brake in case of overspeed.

FIG. 9—COAL HANDLING BRIDGES AT THE PANAMA CANAL
Equipped with direct-current motors and control, and having a capacity of 2.5 cubic yards. These bridges† were installed about nine years ago and originally used for handling concrete.

TROLLEY

The trolley runs on a horizontal track lengthwise with the bridge and carries the hoisting mechanism, and usually the operator. Two motors are generally used for operating the trolley, although a single motor may work out best with some mechanical arrangements. The usual method of control for a trolley provides for dynamic braking, as well as power connections. The central position of the handle represents the *off* or stationary position of the trolley. The movement either side of the *off* position provides the dynamic brake connections. After the master switch handle has passed through these brake notches, it comes to the power notches for either forward or reverse connections. To start, the handle is moved through the brake notches and the power notches; in stopping, a gradual movement of the handle towards the central position applies the dynamic brake with increasing strength until the central position is reached, where the mechanical brakes are applied and the trolley is stopped.

FIG. 10—15 TON ORE REHANDLING BRIDGE
Equipped with direct-current motors and control.†

The complete schematic diagram is shown in Fig. 4 (a) using two motors, the armatures of which are connected permanently in parallel and the fields in series. In the power position, shown in the second diagram, the motor is connected directly across the line and a shunt is provided around the series fields through switch *9* and resistance *2*. This shunt is necessary, as the field coils are designed to carry the full-load current of one motor only and the current of both armatures passes through the fields in series. Half of this current must be shunted in order to give normal field strength and to prevent overheating. The speed of the motor is controlled by closing switches *10* to *13* inclusive, which short-circuit the resistance in series with the armature. Fig. 4(d) shows the same connection with the current passing through the armatures in the reverse direction.

The brake connections are shown in Figs. 4 (c) and (e), the only difference being the direction of current through the armatures. The shunt around the field coils is disconnected and current is applied through

†Bridge built by the Wellman, Seaver, Morgan Company.

switch *8*, resistance *3*, the field coils and switch *2* to the line. The armatures are connected in the closed loop through the starting resistance and switches *3*, *4*, and *6*. This causes the motor to operate as a shunt generator, the amount of dynamic braking being controlled by closing switches *10* to *13* inclusive, which decreases the resistance in the armature circuit. When the mechanical brakes are released by an electromagnet, the magnet is provided with a shunt winding, which is disconnected in the *off* position. Where a single motor is used, no shunt connection is required around the series field, as provided for in switch *9* and resistance *2*; otherwise, the connections are the same. Sometimes two motors are provided, each with a separate controller. When this is done, it is desirable to use double pole switches and common accelerating relays, Fig. 5, so that the rate of acceleration of both motors is maintained constant and there is no danger of connecting the motors to the line in reverse directions.

BRIDGE

One or two motors are provided on each pier of the bridge for moving it along the track. These motors are provided with an ordinary reversing controller having a slow-down point by using a resistance in shunt with the armature. The friction brake is released by a shunt magnet, which is disconnected, thereby setting the brake, only in the *off* or central position of the master switch. Usually, two separate master switches are used, as the two piers of the bridge may not always move at a uniform rate, due to slippage and other causes. If one pier moves faster than the other, the proper manipulation of one or the other controller will straighten the bridge. Usually, limit switches are provided for automatically disconnecting the leading motor in case the skewing of the bridge exceeds the safe limit.

The Design of Automatic Switching Equipments

For Synchronous Converter Substations

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Westinghouse Electric & Mfg. Company

In an automatic substation, the converting apparatus must be started, synchronized and connected to the bus-bars with the correct polarity, whenever it is needed to carry the load; and it must be shut down whenever the load drops below a certain value. Its operation under every contingency, must be foreseen and provided for. Maintenance of good service under all conditions is the prime requisite; but this very requirement necessitates protection of the apparatus from damage. It must be guarded against overloads, overheating, flashing and other operating difficulties, and still, unless actually injured, must be ready to start again automatically as soon as the abnormal conditions have passed. An automatic substation equipment must provide protection against every conceivable form of trouble and must discriminate between those cases of trouble which are transient and will not prevent restarting, and those which are of such a character as to require attention before resumption of service.

STARTING

The most common method of starting includes a contact-making voltmeter connected to the trolley which closes the starting connections, when the trolley voltage is lowered by the approach of a car or train. It is necessary with this scheme to keep the trolley energized from one station continuously in order to hold the voltmeter contacts in the other stations open. An objection to this method is that after a line interruption, where several automatic equipments are used, all of the equipments will start at the same time. This may result in a surge. The same thing will result on a system when the first car out in the morning gets beyond the first station. The voltage drop in this case will be the same to the extreme end of the line, if no other manually operated station is connected to the trolley. A manually operated station at each end of the line, entirely obviates any such difficulties.

There are some operating conditions that are best met by a semi-automatic system in which the starting and stopping of the station is governed from a remote point through a control circuit of one or more wires. This remote control may also be operated by a phantom circuit on the transmission line, provided no grounded neutral connections are made.

Several stations may be operated over one control circuit, which may be either metallic or phantom, by the use of synchronized selector switches similar to those used in automatic telephone exchange systems. This method, however, is liable to be too complicated for ordinary operating conditions.

For small lines with a single station, the trolley is kept energized from a separate source of power of limited capacity, being only sufficient to handle the station lighting and other small demands. The substation is started when a car is started. There are numerous small systems where an arrangement of this sort would allow of a relatively large saving in labor and power cost.

Another method of starting is by means of a track circuit supplied by a low-potential transformer in a manner similar to the alternating-current system of block signaling. With this system, the automatic station would be started only when a car entered the section to be supplied from it. The sections would be divided by the usual impedance bonds, to prevent operation of a

station in one section by a car in the next. This method has the objection that if one station is out of order, the next station will not be started to help it out, as would be the case with the drop in potential method. Still other possibilities exist in the superimposing of relatively high frequency potentials on the trolley through condensers. This is not a practical development at the present time and will require considerable experimental and development work before satisfactory operation is assured.

POLARITY

A synchronous converter has certain inherent requirements that must be met by the starting device. Principal among these is insuring proper polarity before connecting it to the line. The simplest way by which this may be accomplished, is that which most nearly approximates the method commonly used in manually-operated stations. This is reversal of polarity, when necessary, by means of a field reversing switch, the operation of which causes the converter to slip a pole and pull into step with the required polarity.

SYNCHRONISM

Another point that must be provided for is a means for transferring the alternating-current leads from the starting to the running taps when synchronous speed has been attained. It is necessary that proper polarity shall have been attained before this transfer is made and it is even more important that the transfer should not be made until the converter is in step with the source of supply. Several methods of accomplishing this result are possible. A fixed mechanical time element can be used, so set that the converter has ample time to reach synchronous speed under all conditions. However, if sufficient time is allowed to meet all conditions, then the time required in starting would be objectionably long. If the setting is shortened to the average time required then, due to cold oil, low voltage or some such cause, the converter might be thrown on the line out of step. This is liable to cause the converter to flash over. It may also result in disturbances in the high-tension line, of such magnitude that other synchronous apparatus would be thrown out of step.

Another method of indicating synchronism is to use a centrifugal switch driven from the converter shaft. This method is faulty in that it is impossible to calibrate such a device within allowable limits. A combination of fixed time relay with the centrifugal switch will obviate the major objections to the above schemes but still is not a positive indication of the synchronous condition of the converter. This latter method however is being used in a number of automatic substations with apparently good results.

The most desirable method apparently is to use the same indication that is used in manual operation. This is the reading of a polarized voltmeter. The converter manifestly cannot deliver unidirectional current from the commutator until it is running in synchronism with the supply. This is consequently a positive indication of the synchronous condition of the converter and the switching operation may be completed as soon as this condition is reached and polarity is correct. With this method the station may be put into service in the shortest possible time. This is of especial value when the holding relay is set for a time which will permit only a normal service stop of a car without causing the station to shut down. If a car slightly oversteps this time and starts up immediately after the control has opened, this method of starting will allow the converter to be connected to the line more promptly, as with the armature coasting at a fair rate of speed, synchronism will be reached almost at once.

PROTECTIVE DEVICES

After synchronous operation has been obtained it is necessary to provide means for connecting the positive lead to the line. The negative brush may be permanently connected to the rail and the equalizer connection may be made as soon as the running switch is closed, but the positive brush has to be connected to the trolley by a means which will act as a protection against short-circuits and overloads, while at the same time guaranteeing the greatest possible continuity of service.

FIG. 1—500 KW AUTOMATIC RAILWAY CONVERTER SUBSTATION

Of the Ohio Electric Railway Company, at Columbus Grove, Ohio. Showing a rear view of the switchboard and the current-limiting resistors.

The method which has proven best in practice is to insert a limiting resistance in the trolley circuit, when the load exceeds the safe loading point of the equipment. This resistance is of such value as to allow the maximum load condition, occasioned by a short-circuit immediately outside the station, not to exceed the two hour rating of the converter. The resistance is designed to carry this current for five or ten minutes, before reaching red heat, at which point it operates a thermostatic relay, thus opening the control and cutting the station off the line until the resistance has cooled down. If the demand still exists, the equipment will then start again. This resistance is also inserted when connecting the converter to the trolley after starting. This reduces the large rush of current occasioned by abruptly connecting the converter at full voltage to a line at possibly less than half voltage.

The protective devices on the direct-current end should allow the full use of the intermittent rating of

the converter and yet protect it fully against continued overload. To take advantage of the peak load capacity it is necessary that the instantaneous overload relays in the trolley feeder circuits allow the passage of the maximum load that the converter is capable of supplying without commutator trouble. This will ordinarily be from 150 to 200 percent although in some cases it may be possible to have an even higher setting.

To protect against continued overload, it is necessary to have a relay responsive to the heating effect of the load. This can be obtained by a thermal relay operated from a heat coil in the main converter circuit, combined with an overload relay in series, so that if the load causing the overheating has ceased before the thermal relay contacts are closed, the device will remain inoperative. The operation of this device may be used to insert the limiting resistance, thus removing the overload on the machine. If the overload continues after the insertion of the resistance, the resistance will become hot and cut the station entirely off the line until the resistance grids have cooled down.

With the drop in voltage method of starting, the control is held in operation by an underload relay which keeps the station running as long as it is supplying any considerable amount of current. To prevent frequent stopping of the converter during periods of light loads caused by the coasting or stopping of cars, a time device should be used that will allow any stop of normal length to be made without causing a shut down. This device should be capable of instantaneous resetting so that even though the period of underload is within a few seconds of causing the station to drop out, a resumption of current demand will cause an immediate reset to the full time.

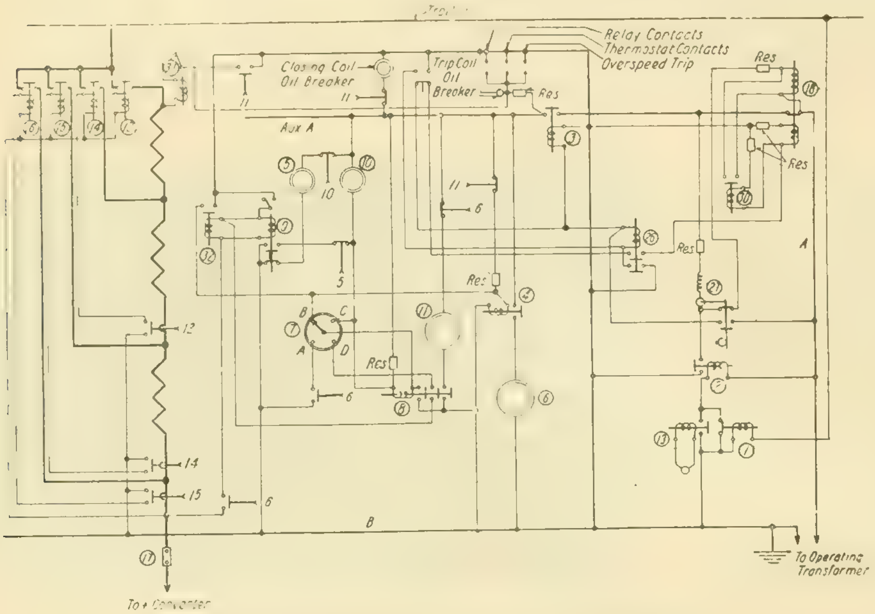


FIG. 2—SIMPLIFIED SCHEMATIC DIAGRAM OF CONNECTIONS

All switches are shown for de-energized condition of switch operating coils 1—contact-making voltmeter. 2—Low voltage relay. 3—Alternating-current shunt relay. 4—Alternating-current shunt relay. 5—Shunt field switch. 6—Starting switch. 7—Polarized motor relay. 8—Alternating-current shunt relay. 9—Field reversing relay. 10—Shunt field reversing switch. 11—Running switch. 12—Line switch. 13—Holding relay. 14, 15 and 16—Line resistance switches. 17—Ammeter shunt 18—Reset relay. 26—Alternating-current shunt relay. 27—Torque-motor operated time delay relay. 30—Resetting lockout relay. 31—Overvoltage safety relay. 32—Field reversal-limiting relay.

Protection against all kinds of operating mishaps is an essential function of the automatic control. At the time of starting it is necessary that the alternating-current supply be adequate to start the converter. The control should be so designed that the line potential will be at least 80 percent of its normal value before the starting switch is closed. Some means must also be provided to insure that this potential is polyphase.

Protection against internal short-circuits in the apparatus should be provided but the relays must be set sufficiently high to permit the passage of any current allowed by the limiting resistance. Means should be provided for attempting to start after an operation of the alternating-current overload relays, as the trouble may have cleared itself. After one or more such trials, the equipment may be locked off the line until reset by the inspector or trouble man.

The usual reverse power protection should be provided as in a manually-operated station. The same overspeed trip is used, but no reset device is needed, as any case of overspeed sufficient to cause automatic cutting out will be the result of such serious trouble as to require the service of an inspector before again starting the equipment automatically.

The main machine bearings should be provided with temperature protection in such manner as to cut the machine off the line if the temperature rises above a safe limit. This indication should be obtained directly from the lower half of the bearing proper and not from the outside of the housing. This thermostatic device should also be capable of being easily reset by the inspector, so that minor cases of trouble that can be remedied without dismantling the bearing, may be taken care of without sacrificing the protective feature.

A TYPICAL INSTALLATION

A concrete case embodying most of the desirable features described above is that of the automatic control installed in the Columbus Grove substation of the Ohio Electric Railways Co. The old equipment in the station consisted of a 500 kw, converter without commutating poles. This is fed through transformers from a 33 000 volt, three-phase transmission system. The switchboard is of the usual type having three panels, one for the alternating-current starting switch, one for the main direct-current switch and circuit breaker, and one for two outgoing feeders. The automatic equipment was installed without disturbing the existing

board, all connections being paralleled with the old equipment.

A simplified schematic diagram of connections is given in Fig. 2, showing the control connections with only enough of the main circuits to provide a clear understanding of the sequence of operations. The alternating-current control circuit is fed from a transformer connected to the high-tension line ahead of the circuit breaker.

The contacts of the contact making voltmeter *1* which governs the starting of the station, close when the trolley potential falls below the point at which the station is to be started. In practice this will usually be at from 60 to 80 percent of the normal trolley potential. The contacts of *1* complete a circuit through the operating coil of potential relay *2*. This is an induction-type voltage relay which will not close its contacts unless the alternating potential is sufficiently high to insure the starting of the converter and the satisfactory operation of the various switches.

Contacts of *2* complete a circuit through timing relay *27* and in turn through the operating coil of master relay switch *3*. This switch energizes the operating bus *aux. A* from which all the various switch operating circuits are supplied. When this bus is energized, three switches are closed at once:—*a*—The closing coil of the circuit breaker; *b*—the field switch *5*, which connects the shunt field across the converter brushes; and *c*—the relay switch *4*, which in turn closes starting switch *6*, thereby applying starting potential to the converter slip rings. Interlock contacts operated by *6* connect the field and armature circuits of polarized motor relay *7*, to the trolley and to the converter brushes respectively. These circuits are not shown on the diagram.

The polarized motor, Fig. 3, consists of a small shunt motor with a permanent magnetic field circuit on which is added a shunt coil energized from the trolley during the starting operation. The permanent magnet provides against the contingency of the station having to start when the trolley is not energized. The armature is connected across the converter commutator brushes during starting. When the converter is first connected across the starting taps, this applies an alternating potential across the relay armature which causes it to oscillate only. As the converter approaches synchronism, the frequency decreases until when it locks into step, a unidirectional potential is applied across the relay armature causing it to revolve in a clockwise direction, if the polarity is correct. A reducing gear is built into the motor frame which drives a revolving brush inside the moulded contact block below the relay base. This revolving brush and its four contacts are shown as *7* Fig. 2. Assuming that the polarity is incorrect, the brush will pass contact *A*, thereby closing relay *8* which will lock itself closed through its own contacts. The brush will next pass contact *D* thus closing a circuit from the negative converter brush (which is permanently grounded) through one of the contacts of *8*, through the coils of relays *9* and *32*, and thence to the positive converter brush. Relay *9* is provided with a holding contact which connects its coil directly across the converter, thus causing it to remain in after the brush has passed point *D* of *7*.

The contacts of *9* cause field switch *5* to open and field switch *10* to close. Switch *10* connects the shunt field across the converter brushes in the reverse direction which causes the converter potential to die away nearly to zero. This causes *7* to slow down and stop somewhere near *C*; it also allows the armature of *9* to be released which in turn causes the field switches *5* and *10* to resume their original positions. This will normally cause the converter to slip a pole and build up in the reverse direction.

If the converter fails to reverse its polarity, the polarized motor will start again in the same direction, causing the field to be reversed again and will continue to do so until correct polarity is obtained or field reversal limiting relay *32* operates. Relay *32* guards against the times when, for some reason, the converter refuses to be reversed by the field. It is a step-by-step device, which after a predetermined number of trials will open the starting switch and allow the converter to drop out of step. After a few seconds it will allow the starting switch to close again and possibly catch the converter in such a manner as to bring it up in the correct direction. This sequence of operations closely imitates the method used in the ordinary hand-operated station for securing correct polarity, except that it is much more likely to secure the desired result at the first trial because the field reversal is obtained at exactly the proper time in every case, which is not true when the human element is introduced.

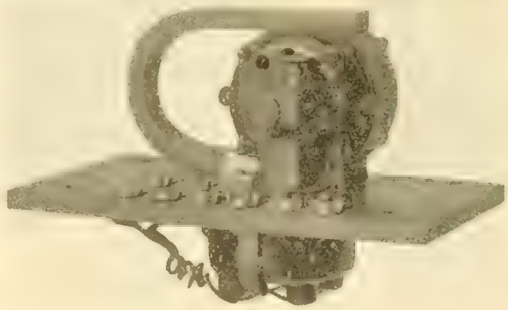
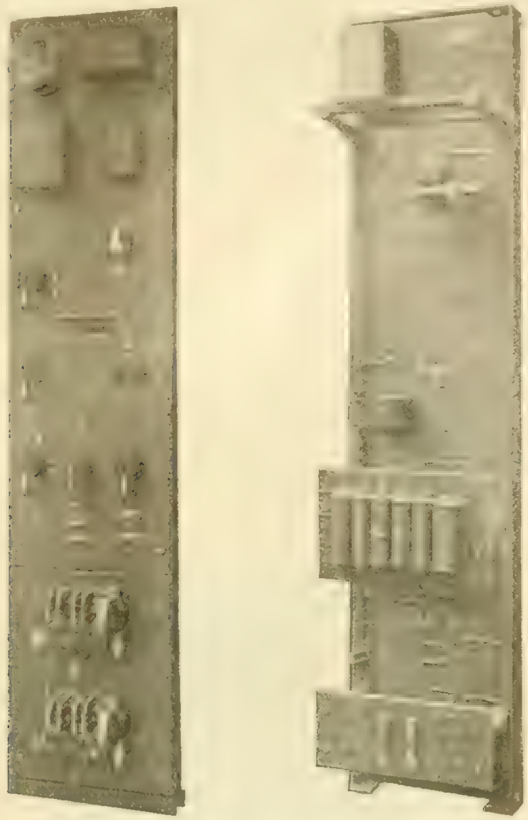


FIG. 3—POLARIZED MOTOR RELAY

A contact on *9* short-circuits the coil of *8* and causes it to open when the field is first reversed. As the converter builds up in the right direction, relay *7* begins to revolve in a clockwise direction. As that brush passes *D*, no circuit is set up because *8* is open. In passing *A*, *8* is again closed. When the brush reaches *B*, the coil of *4* is short-circuited thus causing starting switch *6* to be opened. A circuit through an interlock on *6* and through the main contacts of *8*, closes running switch *11*, thus applying full running potential to the converter rings.

It will be seen that with this system it is not necessary to wait even a short time after reaching synchronism before the transfer to running potential is effected.

On the other hand, the transfer cannot be made until the converter is definitely locked into step and with the right polarity. While the description of the operation takes a relatively long time, the actual operation is carried out in a very brief interval. With a 300 kw, 25 cycle, 750 r.p.m. converter, starting on 28 percent taps,



FIGS. 4 AND 5—FRONT AND REAR VIEWS OF THE RELAY PANEL

The upper row consists of the voltage relay on the left and reverse current relay. The contact-making voltmeter and the holding relay are shown immediately below. The rear view shows the polarized motor and resistors for the relay coils.

the first direct-current line switch was closed 10 seconds after the starting impulse was received; except that when field reversal was necessary, an additional 4 seconds were required. A 500 kw, 500 r.p.m. machine took four seconds longer. When commutating-pole machines are used an additional time of approximately 5 seconds is required to allow the brushes to be lowered.

An interlock on running switch *11* completes a circuit through the contacts of safety relay *31* to the closing coil of the main direct-current line switch *12*. The coil of *31* is connected across the contacts of *12* and is calibrated to operate at 750 volts. As the normally negative converter brush is grounded, there will be a potential of 1200 volts across the coil of *31*, if by any accident the converter should reach this stage of the operation with inverted polarity. If *31* operates it will open the circuit-breaker of *12*, while at the same time tripping the circuit breaker and causing the station to start over again.

Switch *12* connects the converter to the line through the current limiting resistance, thus preventing the sudden surge frequently caused in manually-operated substations when the switch is first closed. Switches *14*, *15*, and *16*, are then successively closed through current limit relays which prevent the short-circuiting of the resistance if the load exceeds their setting. These relays also serve as overload relays to open switches *14*, *15* and *16*, in case of overload or short-circuit on the direct-current system.

As soon as *12* is closed and the converter is supplying current to the line, *13*, the load relay, operates. This relay closes its contacts at approximately 15 percent of the normal station load or any other value that may be found necessary on the individual application. The contacts of *13* are in parallel with those of *1* and serve to keep the station in operation as long as the demand justifies.

The motor operated time relay *27* holds the station on the line during periods of coasting or when the cars are stopped to receive or discharge passengers. It can be set for any period (from three to eighteen minutes) that may be found desirable after installation. This relay will open switch *3* if no demand in excess of the setting of *13* is made on the station within the time setting.

Thermostats are provided over the current limiting resistance grids to cut the station out of service if an overload or short-circuit continues sufficiently long to overheat them. The station will continue to come back

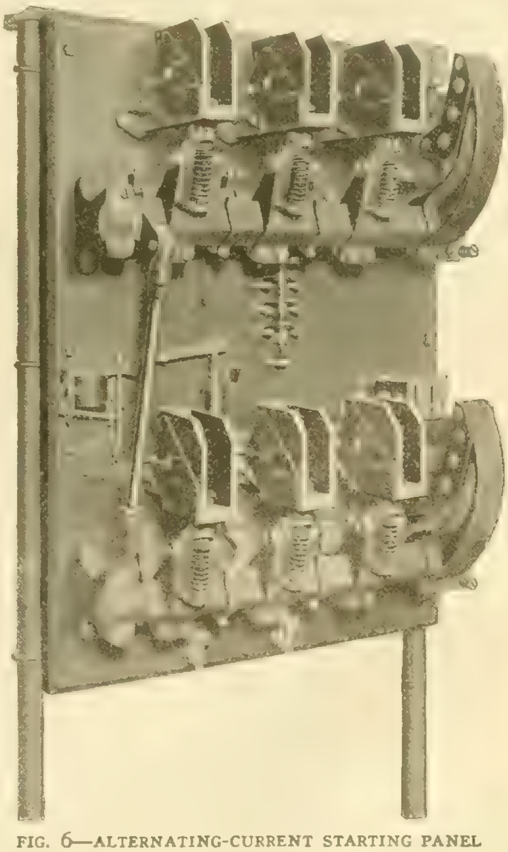


FIG. 6—ALTERNATING-CURRENT STARTING PANEL

Having starting and running contactor switches and interlocks mounted together with the field reversal limiting relay.

into service indefinitely after overheating of the grids if the demand is present.

Thermostats are also provided for the bearings but after these once operate the station is cut out of service until inspected. The bearing thermostats consist

of a copper bulb inserted in the bearing and located so that one side of the bulb is in contact with the bearing metal. The bulb is connected to an external metallic bellows and is filled with a volatile fluid which vaporizes at the maximum desirable bearing temperature, thus expanding the bellows and operating a contact that disconnects the converter from the line. After the bearing has cooled, all that is necessary to reset the thermostat is to press down on the contact rod, thus opening the contacts and restoring the device to its original condition.

An auxiliary switch on the circuit breaker, together with relay *26*, resetting relay *18*, and repeating lockout device *30* is arranged to cause one or more attempts to start after the station has been tripped by the alternating-current overload relays. This is to take care of restarting after a plain overload of sufficient magnitude to affect the alternating-current relays or a short-circuit due to a flashover or some other self-clearing source of trouble. If the tripping still persists, relay *18* is electrically locked open by *30*, which is a step-by-step device capable of being set for from one to four operations. An extra device can be connected to *18* that will signal the dispatcher over the telephone line that the station has been locked out due to trouble. This will also indicate the number of the station when there are more than one on one line.

For use with converters having commutating poles, it is necessary to provide a brush lifting and lowering device. This is arranged with limit switches and interlocks so that the converter cannot be connected to the starting taps unless the brushes are lifted, nor can the direct-current line switch be closed until the brushes are fully lowered. The brushes are arranged to raise immediately after the station is shut down, if the alternating-current service has not been interrupted. If the shut down is caused by failure of the source of supply, then the brushes will be raised when the supply is restored. The lowering operation occurs when the low-tension running contactor closes, taking place in the sequence of operations between the closing of this switch and the closing of the direct-current line switch *14*.

FIELD OF APPLICATION

The principles of automatic switching can be applied to any type of converting apparatus, as for example, to induction motor started converters or to 1200 or 1500 volt service with either one converter or two in series. Where two or more converters are installed for parallel operation, the second and subsequent machines are started by a thermal relay calibrated to indicate the safe loading limit on the machines which are operating. Switches are provided for transferring the control circuits so that the wear may be equalized on the various machines.

For self-starting synchronous motor-generator sets the same general principles of control are carried out as in the converter equipments. Synchronism is indicated by a rectifying commutator on the shaft, which is in effect a small synchronous converter and is used with the polarized motor relay to indicate when direct current is being received from the rectifier.

The present field for the use of the automatic substation is principally in the conversion of hand-operated stations on existing lines for automatic operation. There is also a large field of application to street railway systems in cities where the economies consist mainly in the reduction of feeder copper and feeder losses. In large cities a modified semi-automatic equipment controlled from a central point would be the most suitable. In such cases the saving in feeder copper becomes large while at the same time trolley voltage conditions are improved.

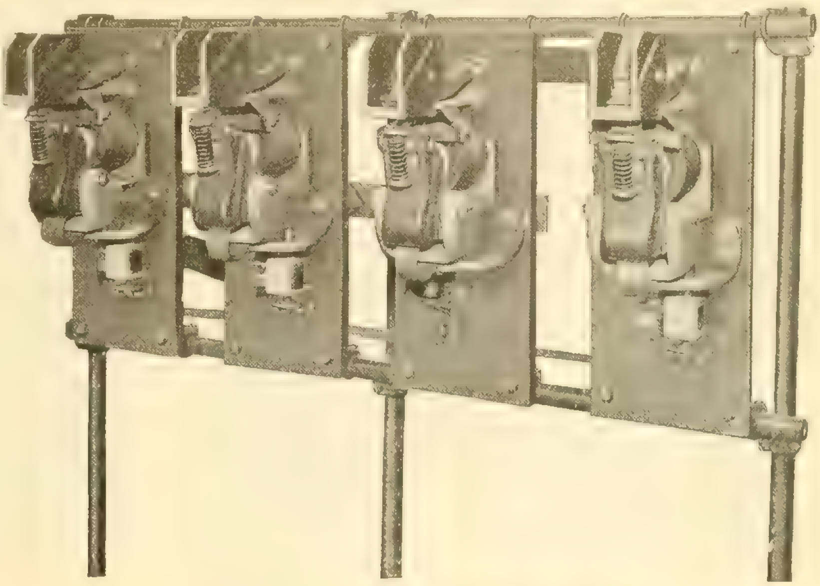


FIG. 7—DIRECT-CURRENT CONTACTOR PANELS

On new traction lines high-voltage automatic stations of small capacity may be installed at relatively frequent intervals. The oil circuit breaker, transformers, and lightning protection would be installed outdoors and the building need be only big enough for the converting and control equipment. This will result in a low building and real estate cost. As the automatic station need not be heated, still another economy is effected by the omission of heating apparatus.

Another large field open for the installation of automatic control is that of the small hydroelectric plant. There are numerous low-head developments that might prove very profitable investments if the cost of attendance could be eliminated. This is a field that is well worth further development.

Combustion Characteristics of Coals

And Selection of Suitable Stoker Equipment

Joseph G. Worker

MANY factors enter into the success or failure o equipment selected for burning different kinds of coal. Not long ago careful consideration was given to the available fuels in different markets, and a particular stoking equipment was selected that seemed to be best suited for a particular kind of coal. In these critical times, however, this viewpoint has necessarily been changed, and it is not now a question of choosing a particular kind of coal and then selecting the apparatus to burn that fuel, but rather the selection of stoking equipment that will burn a wide range of coals. That is, it is not possible now to choose the coal that will be used for any particular industry, but the equipment must be selected and arranged to burn the coal that can be obtained, irrespective of its quality.

In selecting stoker equipment, four factors should be carefully considered. Surprisingly, the most important of these is not the kind of coal to be burned, but rather the load condition of the plant. These four factors, in the order of their importance, are:—

1—Load conditions.
2—Available coal.
3—Draft conditions.
4—Application conditions.

The nature of the load, and the amount of coal to be burned by any particular apparatus, are most important, for the reason that if certain load conditions dominate, irrespective of everything else, stoking apparatus must be selected for that condition. This is also necessary for the reason that different types of stokers can burn the same kinds of coal, but each type of stoker is limited as to the continuous overload capacity that can be successfully maintained and as to its maximum reserve possibilities. For example, an overfeed stoker will burn West Virginia coal very satisfactorily up to possibly 200 percent of boiler rating. On the other hand, the multiple-retort underfeed type of stoker will burn this coal equally successfully at 200 percent of rating, but it is not limited to this capacity, as 300 and 400 percent of rating can be obtained. In a case of this kind, the load conditions would decide the stoking equipment best suited for the work.

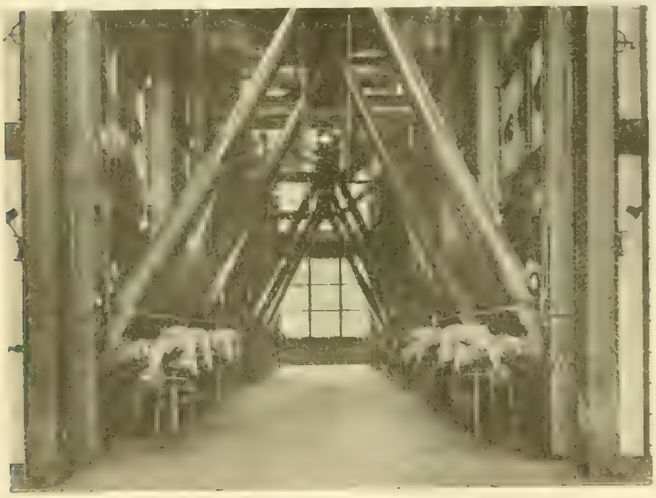


FIG. 1—INSTALLATION OF STOKERS AT NORFOLK & WESTERN RAILWAY COMPANY'S PLANT, BLUESTONE, W. VA.
Where the requirements of extreme flexibility decided that the underfeed type of stoker should be used.

COALS IN UNITED STATES

The combustion characteristics of coals mined throughout the United States vary considerably. Starting in the eastern portion are the anthracites, and such coals as Pocahontas, Clearfield and New River from West Virginia and Maryland, gradually getting into the Pittsburgh and Ohio coals. In the Middle West are Illinois, Indiana, Missouri and Kansas coals which, with their free-burning characteristics, are entirely different from the eastern coals. Going farther west are the Denver Lignites with their high percentage of moisture, which again are different from the lignites of Texas and North Dakota.

FIG. 2—UNDERFEED STOKER INSTALLATION
This plant at one time had the overfeed type of stoker installed, and when the requirements exceeded the reserve capacity of this type of stoker, a careful analysis of the load conditions decided in favor of the underfeed type of stoker. The extent to which the setting is affected by the new installation may be seen by the difference in the brickwork.

Various poor grades of these coals must be contended with by central stations and industrial plants, and the object of this paper is to outline briefly, the action of these coals on different types of stoker equipment. Only the type of stoker equipment best suited for load and coal conditions is discussed; the draft and setting conditions, on the other hand, might be the deciding factor in a particular installation.

ANTHRACITE COALS

The larger sizes of anthracite coal are taken for domestic use, and only the smaller sizes are available for firing steam boilers. On account of the small size this coal is very difficult to burn, and in general nothing has as yet been devised to handle this fuel successfully. On account of the high percentage of fixed carbon in the coal, it is difficult to ignite, and expert firing must

be used to obtain any results at all. In burning this coal, a slight pressure is used under the fire.

A few years ago, evaporative tests were conducted on the overfeed type of stoker with the smaller sizes of Nos. 1, 2 and 3 buckwheat coal and fairly good results were obtained, as given in Table I.

Another test on the overfeed type of stoker gave an equivalent evaporation of 8.4 lb. of water from and

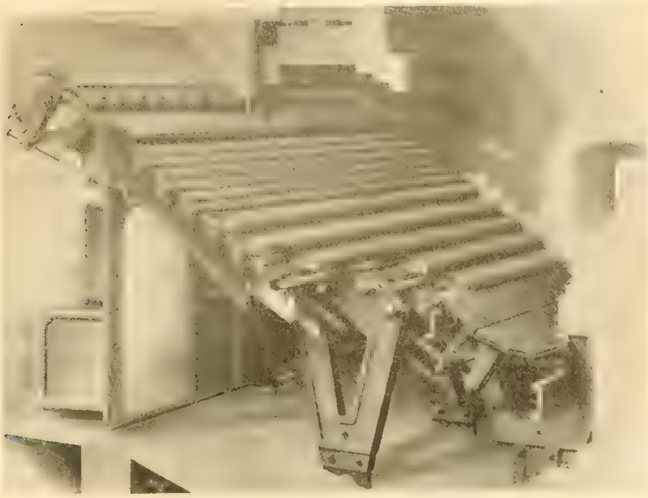


FIG. 3—OVERFEED TYPE OF STOKER

Used extensively for Eastern and Pittsburgh coals where the maximum reserve capacity does not exceed 200 percent of the boiler rating.

at 212 degrees F. per pound of dry coal when using a mixture of run of mine bituminous coal and anthracite buckwheat No. 2, in the proportions of one-quarter bituminous to three-quarters anthracite. This result was obtained when the boiler was operating at approximately normal rating.

TABLE I—PERFORMANCE OF OVERFEED STOKER

Applied to 250 and 500 hp boilers when burning buckwheat anthracite coal.

Performance Characteristics	250 hp	500 hp
Percent of boiler rating during test	77.6	87.4
Duration of test, hours	9.5	10
Temperature of flue gases degrees F.	713	581
Pounds of dry coal per sq. ft. of grate surface per hour	14.5	13.7
Equivalent evaporation from and at 212° F. per lb. dry coal	7.21	8.63
Equivalent evaporation from and at 212° F. per lb. combustible	8.54	10.67

Coal Used—P. & R. anthracite-rice—

95.7 percent passing through a 3/8 inch round mesh.
41.6 percent passing through a 3/16 inch round mesh.
4.7 percent passing through a 1/16 inch round mesh.

Although the handling of this coal on an overfeed type of stoker, as stated above, gives fairly good results, it is not so successful that it could be used generally. That is, each successful installation seems to be surrounded by good local conditions and a good understanding of the requirements of burning this coal. There are many plants in service giving good results.

This coal has been burned on many types of chain grate stokers, but has not, in any way, been successful except on that type using grate bars particularly designed for fine anthracite coal and permitting the use of air pressure under the fuel bed. There have been many recent installations of this type of chain grate for handling small sizes of anthracite coal, and although definite information is not available at this time, this method promises to excel others for this particular coal.

Attempts made to burn the fine anthracite coals on the underfeed type of stoker have gen-

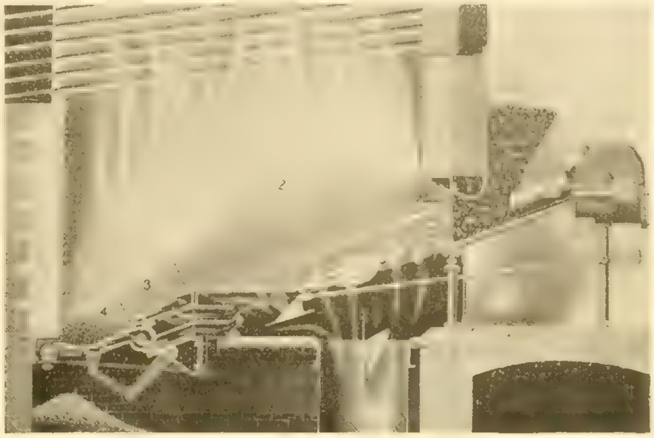


FIG. 4—SECTION OF FURNACE CHAMBER

Showing operating principle and air control of underfeed stoker which burns a wide variety of coals. A wide range of operation and extreme reserve capacities can be obtained from the boilers with this type of stoker.

erally been unsatisfactory. On account of the high fixed carbon content of anthracite coal, there is no question but that it can be handled best on a flat grate or an overfeed type of grate or stoker. While attempts to burn this coal on an underfeed type of stoker have proven unsuccessful, a mixture of Eastern bituminous and anthracite screenings has been burned satisfactorily. The objection, however, to this is that an elaborate mixing scheme must be used to obtain a proper and thorough mixture of the two fuels.

TABLE II—EFFECT OF VARIOUS PERCENTAGES OF ANTHRACITE COAL

Anthracite Coal Percent of Mixture	Cost of Mixture per Ton —Dollars	Cost of Coal per 1000 Lbs. of Water from and at 212° F.	
		Dollars	Percent
0	3.00	0.132	100
25	2.625	0.126	95
33.3	2.50	0.123	93
40	2.40	0.120	91
50	2.25	0.120	91

Recent tests conducted on the inclined underfeed stoker show that about 600 lbs. of a mixture of 50 percent anthracite and 50 percent bituminous coal can be burned per retort per hour. Of course, the object in burning a mixture of bituminous and anthracite coal is to reduce to a minimum the cost of making steam. The relative cost of the anthracite and bituminous coal is, therefore, the main factor. As the percentage of anthracite coal is increased, the total amount of coal necessarily burned also increases, due to the lower heating value per pound of the mixture, and also the lower

efficiency. Test results show that from a zero percent mixture of anthracite with bituminous coal to a mixture of 50 percent anthracite and 50 percent bituminous, the efficiency dropped seven percent. The amount of refuse handled also increases when burning this mixture, and the fixed charges increase due to a reduction in capacity. There is also, as stated above, an additional cost of mixing the two coals. As all of these factors vary for different plants and localities, the percentage of anthracite coal that will permit minimum unit costs differ, so that each individual case must be considered when the individual conditions are known.

To illustrate, in Table II is shown the cost of evaporating 1000 lbs. of water from and at 212 degrees F. on the basis that bituminous coal costs $3.00 per ton and anthracite coal, $1.50 per ton.

EASTERN BITUMINOUS COALS

The coals used in most of the large representative central stations and industrial plants in the East are mainly the semi-bituminous and bituminous coals coming from West Virginia, Pennsylvania, Maryland, etc.

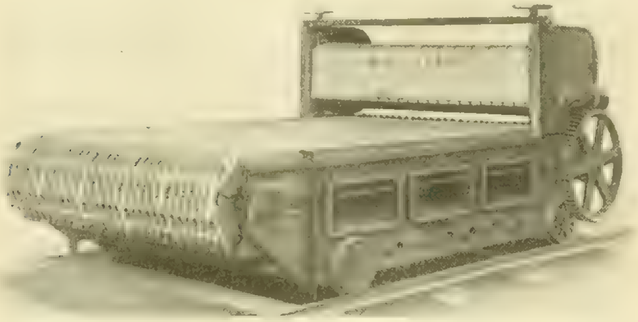


FIG. 5—CHAIN GRATE STOKER

Used extensively for Middle Western free-burning coals where maximum reserve capacity, not exceeding 200 percent of boiler rating, is required.

This coal can be burned very successfully on the overfeed and the inclined underfeed type of stoker; also on some types of single retort underfeed stokers. On account of the characteristic caking of this coal when burned, the chain grate stoker is not suitable. The selection of either an overfeed or an underfeed type of stoker is then reduced to a question of load conditions.

For the large central station plants where extreme flexibility is required in the equipment in order to take care of peak loads and sudden demands for steam, there is no question but that the multiple retort inclined underfeed stoker should be used. In industrial plants, where not more than 200 percent maximum reserve capacity is required in a stoker equipment, the overfeed type of stoker will, in the final analysis, give the best results. For example, with the inclined underfeed type of stoker, a range of operation can be obtained from 50 percent of boiler rating to 400 percent of boiler rating with very little difference in efficiency, as shown in Table III. For the overfeed type of stoker, the range of operation is within the limits of 75 to 200 percent of boiler rating.

PITTSBURGH COALS

A few years ago, the most successful type of stoker for handling Pittsburgh coals was the overfeed type, and even today it is questionable whether, within the limits of the operation of this type of stoker, more satisfactory equipment can be obtained. The inclined underfeed type of stoker, having come into use in the last few years, has shown its ability to handle Pittsburgh coal very easily and, in addition, is giving more satisfactory results than are obtained with the overfeed type of stoker when higher ratings must be obtained from the boilers. Therefore, in the selection of a suitable stoker equipment for burning this coal, the load condition would decide the question as to whether or not the inclined underfeed type would be used or the overfeed type of stoker.

TABLE III—PERFORMANCE OF UNDERFEED STOKER

Applied to a 400 hp boiler when burning Eastern bituminous coals.

Percent of boiler rating during test	50.7	103	145	202	301
Duration of test, hours	24	24	13.25	24	2
Temperature of flue gases, degrees F.	429	465	505	605	743
Pounds of dry coal per sq. ft. of grate surface per hour	7.03	16.4	23.7	33.5	75.2
Carbon dioxide, percent	12.7	14.3	12.7	13.6	15.4
Percent efficiency of boiler, furnace and grate, based on dry coal	70.7	78.02	76.6	75.5	59.8

Approximate Coal Analysis—

Percent moisture	4
Percent volatile matter	24.1
Percent fixed carbon	68.6
Percent ash	7.28
B.t.u. dry	14063

There are many plants in the Pittsburgh district where chain grate stokers are used. While it cannot be said that this stoker is wholly unsatisfactory for these fuels, on account of their coking qualities and the characteristic caking effect, the principle of the chain grate stoker is fundamentally wrong for such coals. The manner in which they act on a chain grate stoker was quite apparent in a test recently conducted on a chain grate stoker having a front coking plate. As the coal ignited, it was pushed off this coking plate by means of plungers and it passed onto the chain part of the stoker in large lumps, resembling blocks. On this particular stoker, forced draft was used. By viewing the furnace fire, it could be seen that the air was going up between these blocks of coke and not through them. In other

TABLE IV—PERFORMANCE OF OVERFEED STOKER

Applied to a 335 hp boiler when burning Pittsburgh coals.

Percent of boiler rating during test	105	210
Duration of test, hours	10	8
Temperature of flue gases, degrees F.	503	718
Pounds of dry coal per sq. ft. of grate surface per hour	17	38
Calorific value of dry coal per lb.	13428	13202
Percent efficiency of boiler, furnace and grate based on dry coal	75.5	68.8

words, it seemed that if one could get into the furnace and paddle down the fuel bed, covering up these holes, proper results could be obtained. In general, this is the action of this coal on any type of chain grate stoker.

COKE BREEZE

In the Pittsburgh district, there is considerable coke breeze that is now without a market due to the fact that there is nothing that can satisfactorily burn it. Many attempts have been made to burn this on the overfeed type of stoker, and all of these have resulted in miserable failures. The best way to burn coke breeze at the present time is on a flat grate with a medium pressure under the grate. A special design chain grate type of stoker is being installed in many plants and promises to give a really successful way to handle this fuel mechanically. Forced draft is used with this stoker. Attempts are now being made to burn this breeze on the underfeed type of stoker, but no commercial success has as yet been attained.

MIDDLE WEST COALS

In the Middle West, where the Illinois grades of coal dominate, in general, the chain grate type of stoker is most suitable for limited boiler outputs—up to about 200 percent of boiler rating. It is surprising, however, to find that in Indiana, where the coal veins are adjacent to those of Illinois, the overfeed type of stoker is more generally used. This is because some of the coals in Indiana have more of a coking or caking nature than a free burning characteristic.

TABLE V—PERFORMANCE OF CHAIN GRATE STOKER

Applied to a 514 hp boiler when burning low-grade Illinois coals.

Percent of boiler rating during test	117	150	160	189
Duration of test, hours	8	6.5	8	8
Pounds of coal as fired per sq. ft. of grate surface per hour	32.9	43.2	44.9	47.3
Carbon dioxide, percent	6.3	8.1	9.5	10.3
Percent efficiency of boiler, furnace and grate based on dry coal	58.6	65.3	65.1	60.8
B.t.u. per lb. of coal as fired	10550	9205	10010	11350

The inclined underfeed type of stoker is now being installed for handling Middle West coal, and the one thing that will make it permanent is the flexibility of the equipment and the possibilities of higher boiler ratings.

LIGNITE COALS

Years ago, the overfeed type of stoker was installed in the west to burn Denver lignites, and was not generally satisfactory. There are many chain grates burning this coal and, in a general way, it might be said that they are fairly satisfactory. There is nothing, however, that has successfully handled this fuel in a commercial way and considerable development work is now being done in an endeavor to apply or change the inclined underfeed type of stoker to handle this coal. This type of stoker has one characteristic which is particularly adapted for lignite, and that is that a very heavy fuel can be carried, and the air supply adjusted, which eliminates the difficulty of blowing holes through the fire and distributing dust and ash onto the heating surfaces of the boiler.

North Dakota lignite coals have been tested, in a general way, on the inclined underfeed type of stoker mainly to ascertain the method of firing, and the characteristic action of this coal on this type of stoker. It was found that the coal was extremely easy to handle and any clinkers that formed could be easily removed at the rear of the stoker. During this test, the results of which are given in Table VII, it was thought that considerable higher ratings could be obtained if the equipment had been originally designed for feeding this grade of fuel. In all of the tests, very little clinker trouble was encountered, and it was not necessary to dump the fire during the seven-hour test.

TABLE VI—PERFORMANCE OF UNDERFEED STOKER

Applied to a 558 hp boiler when burning Illinois Carterville coal.

Percent of boiler rating during test	103	182	212	328
Duration of test, hours	12	12	12	2
Temperature of flue gases, degrees F.	512	489	562	633
Pounds of dry coal per sq. ft. of grate surface per hour	27.7	34.9	37.2	62.3
Carbon dioxide, percent	13.6	13.4	13	15.1
Percent efficiency of boiler, furnace and grate, based on dry coal	77.7	76.1	76.4	
Calorific value of coal as fired, B.t.u. per lb.	11877	10226	11232	11378

Average Approximate Coal Analysis—

Percent moisture	10.3
Percent volatile matter	28.9
Percent fixed carbon	41.8
Percent ash	18.9
B.t.u. as fired	10226
B.t.u. dry	11401

TABLE VII—PERFORMANCE OF UNDERFEED STOKER

Applied to a 600 hp boiler when burning North Dakota lignite coal.

Percent of boiler rating during test	123	139
Duration of test, hours	6	7
Temperature of flue gases, degrees F.	467	467
Pounds of dry coal per sq. ft. of grate surface per hour	32.4	31.4
Carbon dioxide, percent	13.2	12.6
Percent efficiency of boiler, furnace and grate, based on dry coal	56.2	64.6

Approximate Analysis of Coal—

Percent fixed carbon	30.0	30.3
Percent volatile matter	29.7	28.3
Percent moisture	34.4	33.5
Percent ash	5.9	7.9
B.t.u. as fired	7020	7120

There are lignites in Texas that still require some satisfactory means of burning. About every type of stoker has been tried out on this coal but no one seems to have especial advantages that would demand its general use. Attempts are now being made to handle this on the underfeed type of stoker, but it yet remains to be determined whether or not this type will be satisfactory.

The Tendency Toward Outdoor Switching Apparatus

H. G. MacDonald

THE increase in distances covered by electric power transmission lines, and the accompanying increase in voltages to make such transmissions practicable have caused serious consideration to be given to the possibilities in outdoor apparatus. Certain classes of apparatus, such as distributing transformers and their cutouts—both fuse blocks and switches—have been made for out-door operation for many years, but only recently has it been considered possible to make large power transformers with all their controlling and protective apparatus of such design that they can be located outdoors without protection from the weather.

When the size of some of the modern transforming units and the attendant apparatus is considered, the economy effected through placing the units outdoors is apparent. In high-tension bus work, large clearances must be allowed and a building would necessarily enclose a large amount of almost empty space. This bus work can be supported on a skeleton structure which also forms a support for the disconnecting switches. Located below are the transformer units, lightning arrestors and circuit breakers.

The outdoor transformer units present no unusual features but the circuit breaker design presents certain problems which are unique. Provision must be made for operating the circuit breakers without disturbing the weather-proofing and without using time to gain access to the operating means. The position of the circuit breaker mechanism—open or closed—must also be indicated on the outside of the housing.

The pressure set up within the housing by automatic operation under severe overload must have means of relief and the gas formed due to volatilization of the oil during the heat of summer must be gotten rid of. If the apparatus is to be located in a cold climate, the oil must be prevented from solidifying. Heat is not generated in a circuit breaker during normal operation, as in a transformer, and some means must be provided for supplying the heat necessary to keep the oil sufficiently fluid to properly perform its functions of insulation and arc suppression, or else a grade of oil must be used which will remain fluid at low temperatures.

Adequate provision must be made to protect the mechanism from the accumulation of snow and ice in sufficient quantity to interfere with the mechanical functioning of the moving parts. In view of the exposed position, inspection of contacts, etc. will obviously occur at less frequent intervals and there will be periods of considerable duration when access is practically impossible. The mechanism must, therefore, be of such rugged construction as to operate repeatedly during long periods without attention. The apparatus must be made sufficiently tight to preclude the admission of moisture, even under the most severe conditions of rain or snow driven by high winds. Under certain conditions, it must also be protected against dust and sand storms.

FIG. 1—COMBINATION OUTDOOR AND INDOOR SUBSTATION

Electrolytic lightning arresters, oil circuit-breakers, disconnecting switches and transformers mounted outdoors; rotary converters and instrument panels indoors.

Even more than for indoor apparatus must sufficient mechanical strength be provided to withstand internal pressure, as the venting must be less ample than on indoor apparatus. Insulation of exposed parts must be ample to provide against trouble from excessive collection of dirt, moisture, ice or snow. In making up the insulation details consideration must be given to the possible effects of extreme variations of temperature on the material and construction used, not only gradual changes from season to season, but frequent changes from an extremely hot midday summer sun to the succeeding cool night—or a change from summer sun to cool rain as in sudden thunder storms.

On circuit breakers of small and moderate size where the weight of the oil tank and oil is not prohibitive, the most desirable form of circuit breaker is the frame mounting style, with means for the ready removal of the oil tank. With a frame mounted circuit-breaker the mechanism with all its contact details and considerable of the operating mechanism is exposed by lowering the oil tank. This permits a part of the mechanism to be inspected and contact repairs, replacement or adjustment to be accomplished without disturbing the other mechanism or the line connections.

FIG. 2—110 000 VOLT OUTDOOR OIL CIRCUIT-BREAKERS AND TRANSFORMER SUBSTATION

Operating at present at 88 000 volts.

For large circuit breakers, where the task of lowering the tank with oil would be heavy, a platform mounting is necessary In this instance, access to the interior of the tank is secured by the removal of a mechanism cap, which exposes the lever system and presents a sufficiently large opening to withdraw any necessary part. The mechanism is ordinarily so disposed that a terminal bushing complete with its contact details can be withdrawn without disturbing any other details, and the moving contact element can also be withdrawn through the manhole or mechanism cover. Experience has indicated the advantages of a structural frame or platform which permits access to the bottoms of tanks and free air circulation, as this assists in keeping all parts free from rust and corrosion. Tank bases are usually made, however, with openings in the rim so that the bottom can be painted with a long handled brush if the foundation is of concrete or masonry.

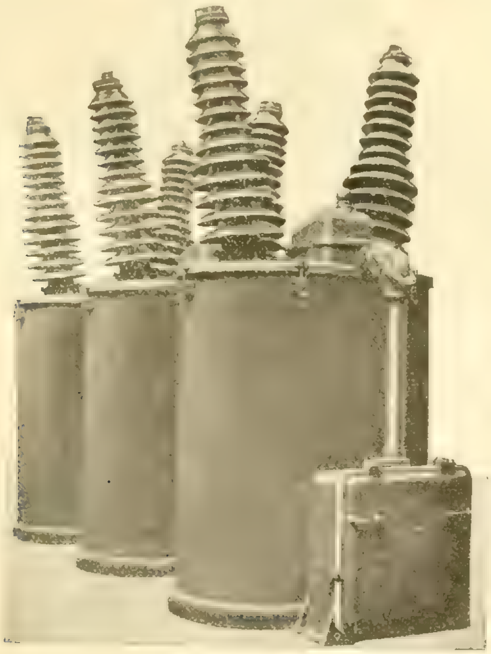


FIG. 3—135 000 VOLT, 400 AMPERE OUTDOOR TYPE, ELECTRICALLY-OPERATED OIL CIRCUIT-BREAKER

Breaking capacity rating, 1500 arc amperes.

It is, obviously, highly desirable that outdoor apparatus be as similar as possible to the equivalent indoor devices, so that the smallest possible variety of spare and repair parts will be required and to permit of interchange of indoor and outdoor apparatus between parts of large power systems. It has, therefore, come about that on such apparatus as may be used in both indoor and outdoor installations, the outdoor style has largely dominated the development of both parallel lines. Certain features are different, as for instance the terminal bushings must be protected from rain and snow and the entire mechanism made weather proof. But a housing which will exclude moisture from the mechanism will also to a large extent prevent the expulsion of oil during operation, which is a highly desirable feature of both indoor and outdoor types. By suitably arranging the various parts an outdoor arrangement of mechanism and covers can be made which is practically as accessible, as simple and as cheap to manufacture as the indoor style. The specifically outdoor features are then the weather-proofed terminal bushings, certain

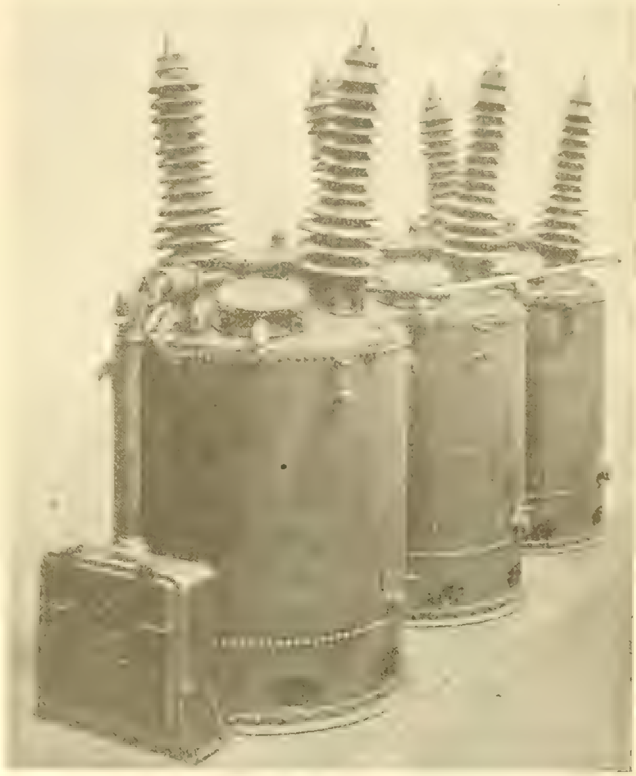


FIG. 4—135 000 VOLT, [illegible] AMPERE, TRIPLE POLE CIRCUIT-BREAKER

Breaking capacity rating, 5000 arc amperes.

venting details and features for protecting the solenoid operating mechanism.

A typical outdoor circuit breaker for medium heavy interrupting service has an elliptically shaped oil tank of steel plate with lap welded seams, and a cast steel top for the tank, of a domed shape for strength. The top is arranged for suspension from a supporting frame and the tank is hung from the top by suitable tie bolts, extending to a framework or supporting grid beneath the tank. An overhung lip around the top is interlocked with the tank rim, restraining the rim, and suitable packing between top and rim insures a weather-proof joint. A suitable removable cover with interlocking rim gives access to the upper portion of the circuit breaker mechanism. Conduit pipe with packing washers and lock nuts affords weather-proofed communication from pole to pole for operating levers and control leads when required. The solenoid-operating mechanism is located at one end of the unit, housed in a case or box with a removable cover having packed joints. This box has conduit pipe for connection to the circuit-breaker mechanism.

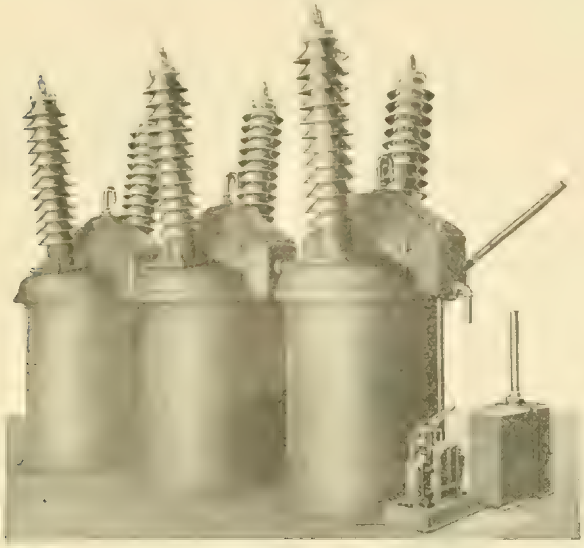


FIG. 5 115 [illegible] VOLT, [illegible] AMPERE OUTDOOR TYPE, OIL CIRCUIT-BREAKER

With cover removed from the electrically-operated mechanism and with hand-closing lever in position; circuit-breaker in open position.

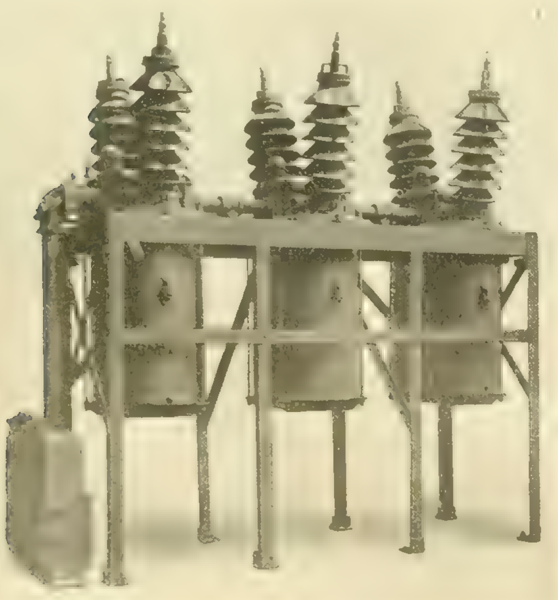


FIG. 6 73 [illegible] VOLT, [illegible] AMPERE ELECTRICALLY OPERATED, OUTDOOR TYPE, FRAME-MOUNTED, AUTOMATIC OIL CIRCUIT-BREAKER

The steel top, in addition to supporting and protecting the operating mechanism, affords an expansion chamber to cushion the pressure incident to circuit interrupting. As considerable oil vapor and gas may collect in this chamber, suitable baffled vents are placed in such positions as to relieve sudden pressures and, in addition, induce a circulation of air through the chamber to drain out the accumulating oil vapor. As the oil is of a more or less volatile nature, this latter function is of considerable importance. To prevent the transmission of a disturbance in one tank to adjacent tanks and to the solenoid box, suitable baffles may be placed in the connecting conduit pipes. Pressure may then be vented to the outside but propagation of pressure from tank to tank will be barred.

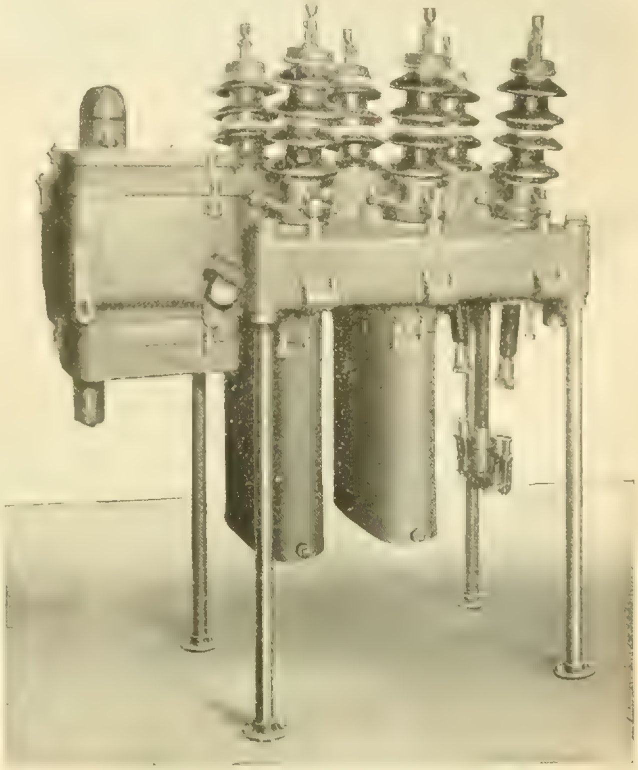


FIG. 7 25 000 VOLT, 400 AMPERE OUTDOOR TYPE, FRAME-MOUNTED OIL CIRCUIT-BREAKER

The terminal bushings are sufficiently protected by petticoated insulators to afford insulation under the most severe conditions of driving rain, wet snow or sleet. It is not uncommon to find the entire structure, including the exposed portions of the porcelain insulators, encased in a coating of sleet or to see snow piled up practically to the entire height of the terminal bushings. Under such conditions it is obvious that a considerable factor of safety in surface insulation is highly desirable.

Circuit breakers for the heaviest interrupting ser-

vice and for high voltages have been made with circular tanks of heavy boiler plate with domed top and bottom rivetted in and with all entrances, such as manholes, of equally strong construction. Commercial specifications have called for tanks capable of withstanding pressures as high as 150 lbs. per square inch. Circuit breakers for the extremely high voltages, which involve long travel of contacts and heavy moving elements, embody special quick break features for the rapid separation of contacts which is essential in high power interrupting devices. By this means extremely rapid contact separation is obtained without the difficulties which would be encountered in trying to accelerate and decelerate the heavy mass of the entire moving element.

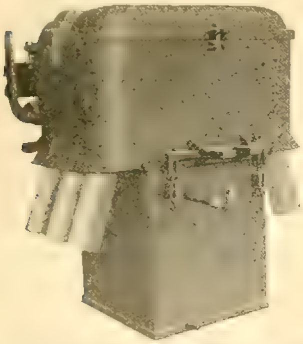


FIG. 8—7500 VOLT, 600 AMPERE, THREE-POLE, SINGLE-THROW, POLE-MOUNTING OIL CIRCUIT-BREAKER

Outdoor disconnecting switches are provided for isolating any circuit breaker for repair or inspection. As a means of placing the control of a unit to be inspected or repaired entirely within the hands of the man doing the work, a small cut-off switch may be placed within the mechanism box so that by opening this switch the operating coils are disconnected and operation from the control desk is impossible.

Where circuit breakers are exposed to temperatures of zero degrees C. or below, ordinary oil becomes sufficiently viscous to seriously impair the efficiency of the circuit breaker. This is due to the slowing up of the opening action due to the heavy oil and also to the

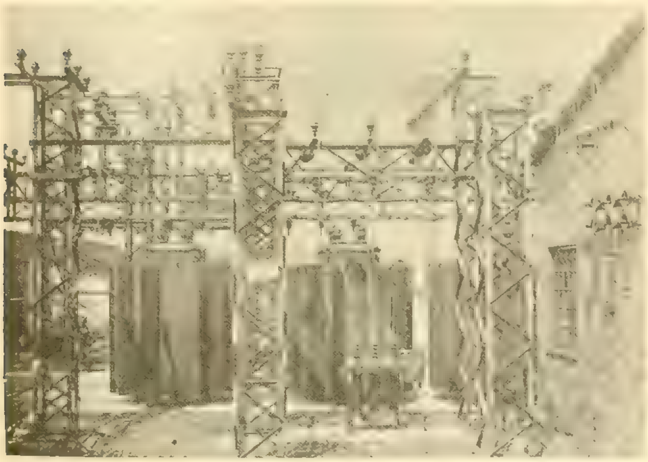


FIG. 9—22 000 TO 11 000 VOLT, OUTDOOR SUBSTATION FEEDING A LARGE STEEL MILL

Low-tension circuit-breakers shown in foreground; high-tension circuit-breakers in rear at left.

sluggish action of the oil itself in flowing in and suppressing the arc. Special grade oil having low freezing characteristics is available to overcome this difficulty but there are cases in which it is desirable to accomplish the same result by other means. For example the low freezing grade of oil is more expensive than the ordinary grade and in cases of large units, or where a considerable number are involved, the cost of the special oil may be excessive. If the range of temperature

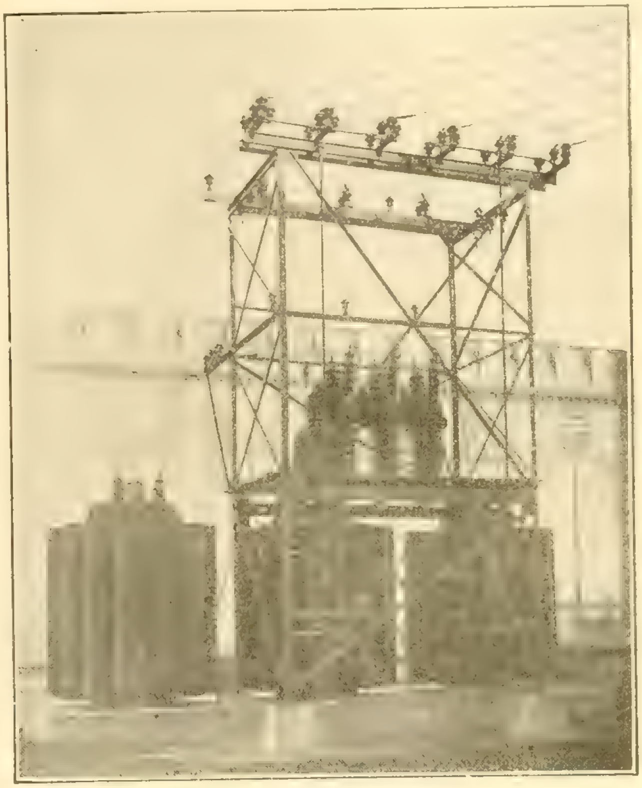


FIG. 10—6000 K.V.A., 13 200 VOLT, OUTDOOR TRANSFORMER SUBSTATION

Circuit-breakers mounted on platform above the transformers.

is large and the summer temperatures are high, the volatilization of the special grade oil may cause doubt as to the expediency of introducing this extra hazard.

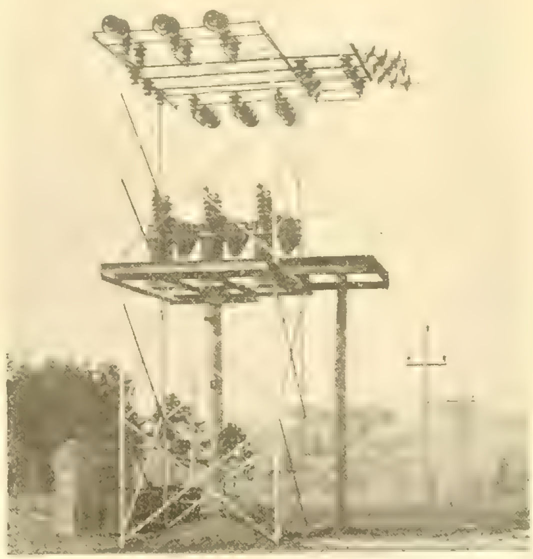


FIG. 11—OIL CIRCUIT BREAKERS ON A FEEDER TAP

From a 44 000 volt transmission line.

In such cases heating elements may be installed in the tanks and put in service during the continuance of dangerously low temperatures. These heating elements can easily be placed so as not to interfere with the ac-

tion of the mechanism in any way. By placing the elements on or near the bottom of the tank, they are away from any high-tension parts and are properly located for the heat distribution by convection currents within the oil. The amount of power consumed is small and can usually be taken from station auxiliary or other low-voltage circuits. It is entirely possible by the use of suitable thermostatic devices to make the control of the heaters automatic. In circuit breakers of the frame mounted style the heating element connections are arranged so that the lowering of the tanks automatically disconnects the heaters.

For automatic overload protection bushing-type current transformers are embodied in the structure of the circuit-breaker. The transformer secondaries are connected through conduit to suitable trip coils on the operating mechanism. Where the conditions of installation and operation require, additional housing or boxes can be added for the protection of overload or other control relays, so that the entire installation of circuit breakers and automatic protective devices can be made self-contained and integral.

Position indication may be afforded by various means. The position of the closing handle socket may indicate whether the contacts are open or closed, or an arrow or pointer may be actuated by some movable part of the mechanism which extends to the outside of the enclosing box. Remote indication may be afforded by signal lamps located at the control board or other convenient place. A small switch, so connected to the operating mechanism as to transfer the lamp connections as the contacts pass from one position to the other, is part of the usual equipment. Emergency operating means is provided so that, in case of failure of control current from any cause, the circuit breaker may be operated manually. This may consist of a removable lever such as would ordinarily be provided with manually-operated circuit breakers.

High Voltage Circuit Breaker Details

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Westinghouse Electric & Mfg. Company

WHILE high-voltage oil circuit breakers are fundamentally the same as those for lower voltages, they are quite different in proportions and details. High voltage necessitates greater insulation distance between conducting parts and the grounded tank and mechanism; so larger oil tanks are used, in sizes that are comparable with those of the larger transformers. For higher voltages, the simple porcelain terminal bushing is not satisfactory and the stronger and more effective condenser type is used. The higher voltages also require a greater travel of the moving contacts and wider separation of the fixed contacts. For this reason the moving parts are heavy and difficult to accelerate and decelerate. Now a high rate of acceleration is desirable in order to reduce to a minimum the time that the arc persists between contacts. One solution of this dilemma consists of an ingenious type of contact that separates at high speed and still requires only moderate velocities of moving parts.

A circuit breaker element that is typical of all that has been mentioned is shown in Fig. 4.* It has a rating of 135 000 volts and 400 amperes and will break circuits successfully with 5000 amperes in the arc. The terminal bushings of this circuit breaker will withstand a dry flashover test of 400 000 volts, and a wet flashover test of 300 000 volts.

The tanks are an innovation in this type of service in that they are circular. Heretofore elliptical tanks have been used almost exclusively in high voltage circuit breakers because they are more compact and require less oil. In rupturing circuits carrying large amounts of energy, however, high pressures are developed within the tanks. The circular type offers much greater resistance to distortion from these pressures. The top and bottom are spheroidal in shape so that flat

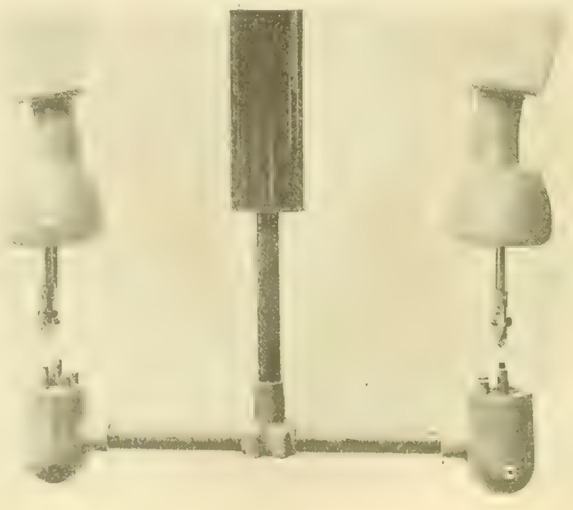

FIG. 1—CONTACT DETAILS
Showing the instantaneous position just after the latch has been released, corresponding to the position shown in Fig. 4.

surfaces are consistently avoided. The tanks are of boiler plate, three-eighths inch thick and are designed to resist a sustained internal pressure of 150 pounds per square inch.

The lower end of the condenser type terminal bushing is enclosed in a porcelain arc shield for pro-

*In the article in this issue on "The Tendency Toward Outdoor Switching Apparatus" by H. G. MacDonald p. 125.

tection from arcs. Between this arc shield and the stationary contact is the metal static shield for dis-

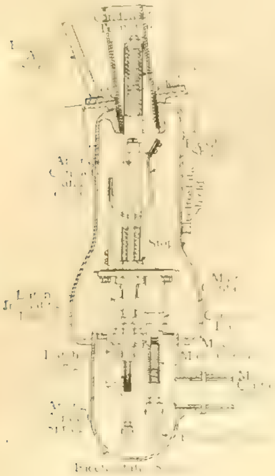

FIG. 2—CIRCUIT-BREAKER IN THE CLOSED POSITION

As shown in Fig. 5. The main and arcing contacts are closed and the latch tongue is seated in the latch.

FIG. 3—MAIN CONTACTS SIX INCHES OPEN

With arcing contacts closed and latch holding. The arcing contact spring is compressed in this position.

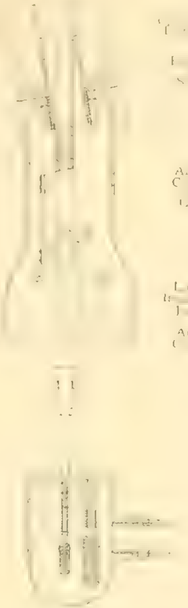

FIG. 4—MAIN CONTACTS EIGHT INCHES OPEN

At this instant the latch has released and the arcing contacts are separating at a high velocity.

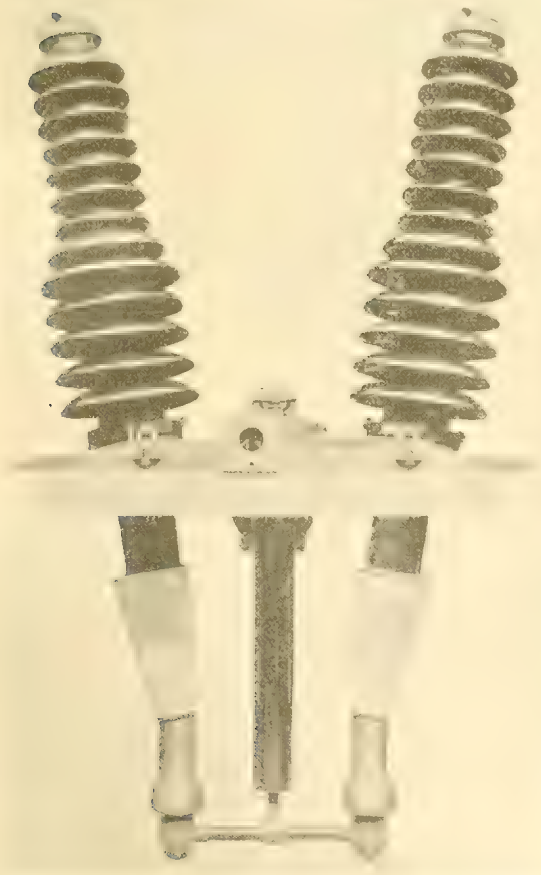

FIG. 6—SINGLE-POLE OIL CIRCUIT BREAKER UNIT WITHOUT TANK

tributing the electrostatic stress uniformly over the surface of the terminal bushing. The contacts are of the butt type, each assembly having two current-carrying and two arcing contacts. The latter are designed to take all the arcing so that the main contacts will not become pitted or burned by the arc. The whole stationary contact is enclosed in a metal hood which distributes the electrostatic stress that would otherwise be excessive on the sharp corners and edges of the contact mechanism.

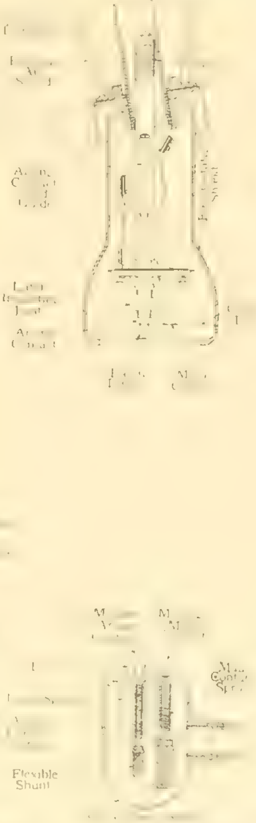

FIG. 5—CIRCUIT BREAKER IN THE OPEN POSITION

The arcing contacts embody a novel feature in that they remain in contact with similar arcing contacts on the movable contact during part of the stroke of the latter. When the switch is closed the two sets of arcing contacts are latched together. In the opening operation the main contacts separate at once but the latch holds the arcing contacts together, the upper ones being pulled down against the compression of a spring. After the moving contact has dropped seven inches this latch releases and the springs retrieve the upper arcing contacts, breaking the circuit quickly. Thus the stationary arcing contact is stationary in name only and a high speed of final break is obtained. The sequence of operation is given in Figs. 2, 3, 4 and 5, showing the opening of the contacts in successive stages. The total travel of the moving contacts is 22 inches, making a total break of 44 inches in each line.

The circuit breaker may be operated electrically or by means of a hand lever. Remote electrical operation is secured by two solenoids, one for closing and one for tripping the breaker. The pushing of a button on the switchboard accomplishes either operation by energizing the proper solenoid, a signal switch on the circuit breaker closing a lamp circuit, which indicates to the operator the completion of the operation. All three poles are connected mechanically and operate simultaneously.

In the bottom of each tank is an electric heater for raising the temperature of the oil in cold weather. The heaters will keep the oil at 32 degrees F. when the outside temperature is zero degrees F. Each heater requires 3.5 kw at 120 volts. This heater serves to keep the oil in proper condition in the severest winter weather.

The Engineering Evolution of Power Plant Apparatus-XXVII

A Historical Review of Steam Turbine Progress

Francis Hodgkinson

COUPLINGS

In the earliest machines, the turbine and generator shaft were each provided with a square formed in the end of the shafts over which fitted a loosely fitting sleeve. This was subsequently replaced with a claw-type coupling Fig. 34. This coupling is of the so called flexible type which, however, does not permit of successful operation with material misalignment of the turbine and generator shafts. With misalignment there is a slight variation of angular velocity which, on account of the inertia of the revolving parts, causes a heavy intermittent stress on the driving horns, each horn in turn having to accelerate the masses slightly at each revolution. There were a few cases where breakage occurred, although the stresses due to normal operation were quite low. Of course, the greater the length of the coupling between the sets of driving horns the more truly flexible it becomes.

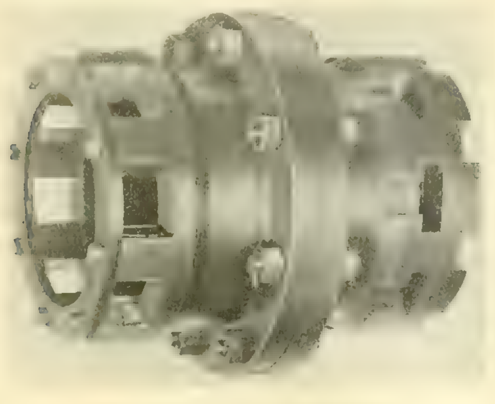

FIG. 34—CLAW TYPE COUPLING

In the later type couplings shown in Fig. 35, circular driving pins having considerable overhang are employed, thus permitting a slight flexibility of the pins themselves. That is, they may deflect slightly without strain. No breakage has occurred with this design.

LUBRICATING SYSTEMS

All turbines have been provided with lubricating systems operated by pumps directly driven by the turbine. In all but the smallest sizes, this is relayed by a separate steam-driven pump, which is for use only in starting and stopping. With time, however, the lubricating system has become more elaborate. It is generally recognized that the life of the oil is much increased by an ample reservoir. The longer the rest the oil has between the times of actual use in a bearing, the better; hence the capacities of reservoirs have been materially increased, a 20 000 kw turbine having a 20 barrel oil tank. Later machines are provided with elaborate strainer systems which may be cleaned while the turbine is operating.

A system of fractional filtration is coming into general use, there being provided in the power house a first class filter system of moderate size, capable of filtering continuously a few percent of the oil actually being used. The turbine oiling system is provided with an overflow arranged to drain the dirtiest oil from the bottom of the reservoir. A supply of clean, pure oil commensurate with the capacity of the filter system is then delivered into the turbine system; the same amount of dirty oil overflowing to be refiltered.

Oil coolers or their equivalent are always necessary. It has been the custom of the Westinghouse Company always to employ a separate cooler. The practice of water cooling the bearing itself, or of embedding cooling coils in the babbitt, while highly efficient from the standpoint of heat transfer per unit of surface, has never been resorted to because of the impracticability of cleaning. A modern cooler is shown in Fig. 36, the water making many passes at high velocity through the tubes, the oil circulating outside the tubes. The cooling surface merely lays in a cast iron box, the water connections being more or less flexible. Proper provision for expansion is evident, as is the means by which the whole element may be lifted out for cleaning.

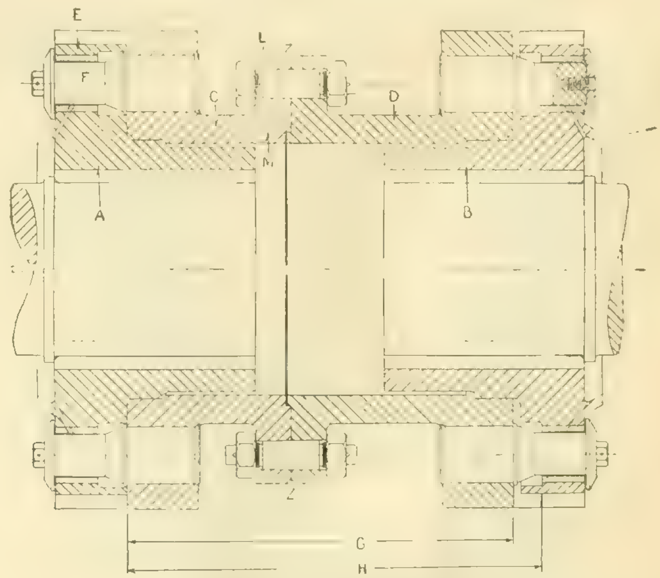

FIG. 35—PIN-DRIVE COUPLING

Oil is used at a temperature of 100 to 140 degrees F., a temperature conducive to any chemical action; it therefore must have no tendency to turn acid, which generally precludes the admission of any animal or vegetable oils. It is found that some higher viscosity

oils, while they may contain nothing but pure mineral stock, have a tendency to emulsify. This is particularly true in cases where the reservoir system is not large and the oil gets insufficient rest. A viscosity as low as 150 secs. Saybolt at 100 degrees F., is satisfactory for turbines. In the case of geared units, however, a viscosity of 250 to 350 secs. Saybolt at 100 degrees is recommended; the turbine itself operating equally well with this higher viscosity, the only difference being a slightly higher bearing temperature and a little more cooling required. The ideal lubricant is the fluid having the greatest adhesion and the least cohesion. The requirement of the bearing is that the relatively moving surfaces be adhered to by the fluid, the fluid itself being sheared between the surfaces, a definite film adhering to each surface. The work of the bearing, or the bearing losses, depends on the resistance to this shear, which is a function of the viscosity. Inasmuch as the viscosity becomes less with increasing temperatures, bearing losses may be maintained at a minimum by operating with high oil temperatures. Decreasing viscosity with the increase of temperature, reduces the losses so unless there is something the matter, a bearing will reach a definite temperature and stay there. It is self-regulating in that respect. While turbines operate

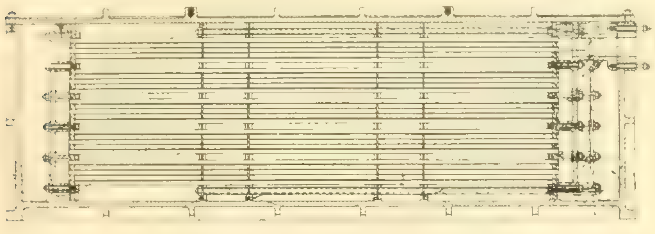

FIG. 36—COOLER FOR LUBRICATING OIL

well with oil temperatures as high as 160 degrees F., no attempt is made to state what may be regarded as the limiting temperature, or in what respect the life of the oil is reduced by continued operation at high temperatures. Inasmuch as the oil consumption of a turbine, after the system has once been charged is practically nothing, the question of price at the expense of quality and suitability should not receive consideration.

EXHAUST PASSAGES

More attention is being given to the exhaust passages of turbines, that the steam may leave the turbine without eddies in the exhaust chamber. In older designs, it was not uncommon to find hot and cold spots with the turbine operating under light loads, and particularly on a change of vacuum, doubtless inducing considerable temperature strains. Some later large machines are projected with what may be termed "stream line exhausts", the steam being divided up, as it leaves the last row of blades, into a number of easy curved passages leading to the exhaust opening.

With high-speed machines, the exhaust passages have greater physical dimensions than anything else about the machine, the turbine almost appearing to be all exhaust chamber so any further attempt to reduce physical dimensions by increasing rotative speeds will not materially affect the dimensions of the whole turbine.

PROGRESS AND FUTURE POSSIBILITIES

Discussion of the general progress of turbine development in the past is not complete without reference to the possibilities of the future. It is plain that with turbines of large size, which deliver to the switchboard 76 to 80 percent of the theoretical energy available from the steam expanding between the limits specified, further improvements in the turbine itself will not materially raise this efficiency, and that further improvement in central station economies must be looked to from causes other than the steam turbine. This is a subject of the greatest importance in view of the rapidly increasing cost of fuel and justifies considerably more capital expenditure for economisers and other plant apparatus which will reduce fuel cost.

Attention at the present time is being directed to employing higher boiler pressures; viz., pressures as high as 600 lbs. Today 200 lbs. pressure, 200 degrees F. superheat is regarded as a more or less every-day operating condition for large plants. Steam generated at 600 lbs. pressure, having exactly the same heat content as that contained in 200 lbs. pressure and 200 degrees F. superheat, will have a superheat of approximately 128 degrees F. This expanded to 29 inches of vacuum is theoretically capable of giving 13 percent more energy than when generated at 200 lbs. Doubtless, when operating under these conditions, the turbine will be of lower efficiency. The high pressure element will be less efficient on account of the great density and the small volume of the steam, and on the other hand the low pressure elements will be less efficient because of the great amount of water precipitated by the steam expansion from the high pressure, introducing a brake in the turbine. However, it is reasonable to suppose that the turbine will avail itself of at least 50 percent of this 13 percent possibility, producing a net saving of six or seven percent. What may be expected to be derived from higher pressures is exhibited in Figs. 37 and 38, plotted for various pressures.

Another source of improvement of performance in large multiple-cylinder machines may be obtained by intermediate reheating, the steam expanding from a high pressure and superheat through a high pressure element to a pressure of say 40 lbs. absolute, where nearly all the superheat has disappeared; the steam then being passed through a separately-fired superheater and raised to approximately its original temperature, thus giving a nearly dry cycle to the whole steam expansion. The addition of an intermediate reheater to such an installation would be expected to secure an improvement in total B. t. u. supplied of three percent. Until lately, however, the capital expense involved would hardly have been warranted.

Much more than formerly, attention is being given to the subject of feed water heating and means are available for providing a heat balance between the feed

water heating system and the main turbine unit, valves being provided which will take steam from the turbine whenever there is a deficiency of auxiliary exhaust steam for heating feed water and take steam from the heating system when the feed water heater is incapable of condensing all of the exhaust steam from the auxiliaries. Valves are also available which, when the conditions demand, will take steam from a higher pressure stage of the turbine in one case and admit steam to a lower stage in the other.

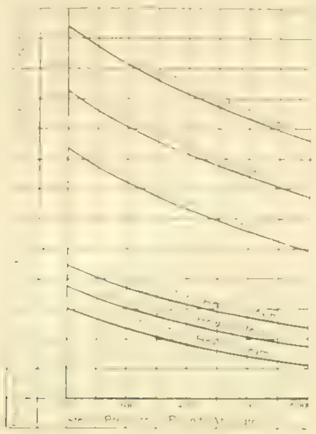

FIG. 37—COMPARATIVE PERFORMANCE CURVES

Of a 60 000 kw, three cylinder, 1800 and 1200 r.p.m. turbogenerator unit. Performance given at 45 000 kw output, when supplied with steam having a total heat (above water at 32 degrees F.) of 1280, 1300 and 1320 B.t.u. per pound at various steam pressures.

A heat balance system has been proposed, employing electric motors for driving the auxiliary machines and these in turn operated by a special generating unit, the generator being driven both by a non-condensing steam turbine and an electric motor operated from the main busbars, the flow of steam to the turbine being controlled by the pressure in the exhaust and hence by the needs of the feed water heater. At times of excessive demands for feed water heating, the motor may give energy to the system and conversely when there is a small demand for steam for heating feed water, the energy for driving the auxiliaries will in part, come from the main units. The auxiliaries, being motor driven, have the advantage of reducing the general dirtiness, heat, and overcrowding to be found in the basements of many power plants on account of the steam and exhaust piping of the many small turbines. The general prejudice against electric motors for condenser and other auxiliaries would seem to be giving way in view of greater ruggedness of electric motors and the safety of their circuits. The heat energy actually required to operate the auxiliaries with such a system would be far less on account of the better performance of the large turbine unit as compared with the number of small non-condensing auxiliary turbines, in spite of the electrical losses involved.

Further economy may be expected by making more extended use of the economiser. Until lately it has been considered difficult to operate economisers successfully if the feed water is admitted to them at temperature much below 200 degrees, because of corrosion of the surfaces and the condensation of tarry compounds from the fuel. It is probable that in the future economisers will operate well with the water entering them at 120 degrees or thereabouts, the water being heated to this temperature by a fewer number of steam-driven auxiliaries or by the employment of electrically-driven auxiliaries entirely and bleeding the main turbine at a stage where the pressure is commensurate with that temperature.

The present time is a very important period in the development of the steam turbine. A large number of big units have been built ranging in size from 25 000 to 60 000 kw. Those built by the General Electric Company are of the impulse type, those by the Westinghouse Company entirely of the reaction type, and sometimes a combination of both types, where the complete expansion is carried out in a single cylinder. Of the Westinghouse machines, the increased reliability obtained by dividing the steam expansion in separate cylinder structures is recognized. Some have been arranged with the high and low pressure cylinders arranged tandem fashion, driving a single generator. Others are arranged "cross compound," each turbine element driving a separate generator. The very largest sizes are of three-element design, comprising one high pressure turbine, with a low pressure on either side, each of the three elements having its separate generator.

Some of these units are now in operation, and within another year, a great many will be in service.

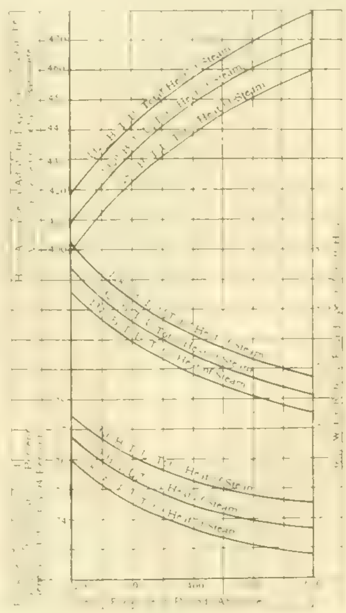

FIG. 38—HEAT AVAILABLE IN ADIABATIC EXPANSION

Of steam expanding to 29 inches vacuum in a 60 000 kw, three cylinder turbogenerator unit, with constant total heat contents in high-pressure steam. Also resultant ideal water rate and Rankine cycle efficiency at 45 000 kw load.

Some of them will be tested for steam efficiency. All of them will give evidence as to their reliability of operation and accessibility for inspection and repairs. The multi-cylinder turbine certainly seems to have much to commend it, if there is anything in the thought that with increase in the capacity of the prime mover, there

should be a corresponding increase in reliability. These very large units, if built in a single cylinder structure, impose grave problems of design, for as the structure becomes larger, the more likely it is to change shape under the varying temperatures within its walls. Also, the hazard is introduced of using higher grade materials to deal with higher stresses, with all the uncertainty which that question involves in the actual securing and testing of such materials with absolute knowledge that the quality of the test specimen will be secured approximately in the finished piece.

We then have the increasingly imminent question of dealing with higher steam temperatures, which does not make the design of turbines any easier, as is well proven in several recent instances. So if we take advantage of the fact that in size alone resides an ability to achieve higher efficiency, then it would seem that the uncertainties of design and construction as regards heat stresses, as well as centrifugal stresses, can best be removed by introducing no new questions. Let us have the high efficiency that comes with large size, and let us add no new problems to detract in any way from reliability. Therefore, divide the unit into elements of such size as bring us within well-tried practice, dealing with no special materials, avoiding widely differing temperatures within the same structure, keeping the high temperatures within the relatively small high pressure element, and be ready, also, for the still higher temperatures of the future. The multi-cylinder arrangement occupies more room, measured in the width of the unit, but less in length; however the turbine room space in this respect is not a problem in most stations. They have the advantage, previously pointed out, that the turbine elements are sensible of being operated separately in the event of derangement of either one of them. Automatic apparatus is provided, when demanded, for any two of the three turbine elements continuing to carry load, should the one be taken out of service, either by the opening of the circuit breaker or by tripping the emergency stop. The compound unit costs more money, but not prohibitively more, if the construction behind its adoption is justified by experience. In view of the present power house costs, there would seem to be no economic need of reducing the cost of turbine units below the amount required to make them as nearly perfect as possible. It is hoped that the time is not far distant when the turbine designer will not have to initiate quite so much as he has in the past; that on the operating side the engineers will test their turbines more generally and will know precisely what results they give in steam consumption, and will take a stronger position respecting the mechanical features of design, details of operating convenience, etc., much as they used to when they dealt with the subject of Corliss engines, and recognize and give consideration to better detail design of not only the turbine itself, but its appurtenances.

From all that has been said it is plain that the progress in the construction of turbines has not been to reduce intrinsic cost. The increased reliability, while sometimes secured by more skillful design, and at even a reduction of cost, generally however, involves greater cost. The higher operating conditions:—pressure, superheat and vacuum, each involves greater expense. The higher vacuum calls for larger low pressure blade areas, as well as an increased number of turbine elements. The higher pressures and superheat both involve more turbine elements, and also preclude the use of cast iron for the high pressure portions, adding materially to the cost of valve gears, etc. Competition calling for the highest performance has brought about the employment of higher design coefficients which introduce still another element of increased cost. The increase in rotational speed for a given size machine is about the only item besides improved manufacturing processes that has enabled manufacturing costs to be reduced.

In spite of this, the price (under pre-war conditions) of large turbine generating units has been reduced to approximately 40 percent of the cost of the earlier large turbines of 5000 kw or thereabouts. The efficiency ratio has been increased in this size approximately eight percent. Considering the larger sizes that now obtain, the cost per kilowatt is further reduced and efficiency ratios have been improved twelve percent. Actual heat consumption of B. t. u. supplied at the throttle has shown a reduction of 24 percent between the 7500 kw turbine of 1905 and the Interborough turbine of 1914.

Comparison of steam engine performances are, however, incomplete without consideration of capitalization, depreciation, etc. Assuming the cost of steam as 15 cents per thousand pounds, a load factor of 75, and 15 percent for fixed charges, a saving of 33 percent is produced by the later of the above two machines.

To make a similar comparison between a modern large turbine installation and the best performance of reciprocating engines, assume:—

	Turbines	Engines
Initial cost per kw of the generating units	$ 8.00	$40.00
Fixed charges, percent	15	15
Pounds steam per kw-hour	11	17*
Cost of steam per thousand pounds	$ 0.15 (at 220 lb. 150° supht.)	$ 0.14 (at 175 lb. dry sat.)
Load factor	75	75
Cost of foundations per kw	$ 0.50	$ 2.50
Cost of condensers per kw	$ 3.50	$ 2.50
Cost of engine room personnel, not including executive administration, per kw per year	$ 0.61	$ 1.57
Oil and engine room supplies per kw per year	$ .10	$ 1.34
Total cost per kw per year	$13.34	$25.29

The modern large turbines have therefore accomplished a saving over the best reciprocating engine installation of approximately 47 percent. The cost of energy has been no doubt reduced to one-half if consideration is given to reduced size of buildings, etc.

*See paper by H. G. Stott and R. G. Pigott, A. S. M. E. 1910.

The Essentials of Transformer Practice—IX

Transformer Insulation

E. G. Reed

THE AMOUNT and arrangement of the insulation in a transformer has almost as much of an empirical as a theoretical basis. The amount of copper in the electrical circuits and iron in the magnetic circuits is a matter of calculation when the characteristics of the materials are known and certain results are to be secured. On the other hand, the amount of insulation to be used in a given place, quite often depends upon its mechanical characteristics, and the stresses which it must withstand during winding.

INSULATION TESTS ON COMMERCIAL TRANSFORMERS

Usually, the tests made on commercial transformers are in accordance with the standardization rules of the American Institute of Electrical Engineers. Disruptive tests are made between the high and low-voltage windings and between the windings and ground. Similar tests are also made between the several parts of either the high or low-voltage windings, when composed of two or more electrically separate parts.

While an over-potential test is made (at a frequency higher than normal to prevent over-excitation of the magnetic circuit), the voltage between turns of the winding is not sufficient to really test the insulation to its normal break down value. The voltage developed at the terminals of the coils limits the extent to which the over-potential test can be carried. It has been proposed that some test be developed by which a surge could be thrown on the transformer, by the use of a discharge from a condenser, duplicating in some measure the transient conditions in service, but so far such a test has not been standardized.

DIELECTRIC CHARACTERISTICS OF THE INSULATED TRANSFORMER

The practical value of insulation resistance measurements on transformers is that they give some idea of the amount of moisture or dirt present, a low insulation resistance value being serious largely because it indicates a probable low dielectric strength of the insulating material and a possibility of failure due to high dielectric loss. Further, an insulation resistance measurement does no harm to the transformer, while a failure under the disruptive test may injure the insulation at the point of failure.

Insulation resistance varies inversely as the cross-section of the insulating material, and this is the reason why high-voltage transformers may have a lower resistance than lower voltage transformers of the same rating. The insulation contact surfaces between windings and iron and between coil windings of high-voltage transformers may overbalance the lesser thickness of insulation used in low-voltage transformers. Dry transformers have resistances of from 200 to 2000 megohms.

The insulation resistance of a small 2300-230 volt, 60 cycle distributing transformer, at various temperatures is shown in Fig. 1. These curves were made from a transformer which passed all standard insulation tests and was therefore suitable for service. The tests were made with the case filled with oil and the transformer heated to approximately 70 degrees C. It was then allowed to cool, taking resistance measurements as the temperature dropped.

The dielectric loss for a 150 k.v.a., 6600-440 volt, 60 cycle transformer is shown in Fig. 2. The test was made under the same conditions used for the dielectric strength test, that is from the high-voltage to the low-voltage winding, with the latter connected to the magnetic circuit. The dielectric loss with this connection is greater than the loss would be with the transformer in actual service, because all of the windings are at the same potential. In service the potentials of the wind-

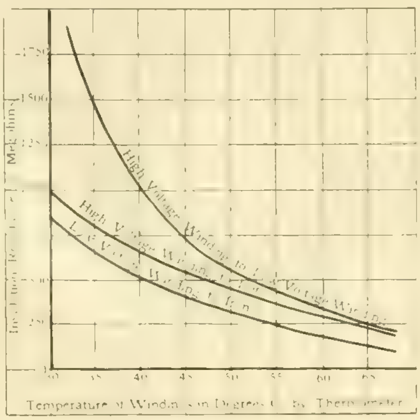

FIG. 1 VARIATION OF THE INSULATION RESISTANCE WITH TEMPERATURE

Of a 2300 to 230 volt, 60 cycle distributing transformer.

ings with regard to each other change from point to point in the coils. The losses in actual operation will be about one-third of the losses indicated on the curve for the same voltage, but changing somewhat with the particular connection used. However, the dielectric loss in a transformer under the most unfavorable conditions is very small as compared with the iron and copper losses.

The dielectric strength of the insulation between the various parts of a transformer must be such that the conditions arising in service, will be met with a reasonable factor of safety. The greater part of the insulating materials used in transformers is cotton and paper fiber.* It is therefore reasonable to assume that a transformer which has operated for a period of from

*Whose mechanical characteristics under operating conditions are shown in Figs. 3 and 4, Part VIII, in the JOURNAL for March, '18, p. 100. Fig. 3 shows that, for the various temperatures, constant conditions are reached in the neighborhood of 100 hours.

100 to 200 days at full load, runs little risk of later burning out under the same conditions.

Since the greatest mechanical stresses are placed on the insulations when the coils are being wound, after the winding and assembling are accomplished, a considerable diminution of the mechanical strength of the insulation is then permissible. Perhaps one-half or one-quarter of the original strength would suffice, particularly since the insulating materials are re-enforced by the impregnation treatment.* The heat resisting properties imparted by the impregnation treatment form another factor of safety in addition to that possessed by the unimpregnated paper and cloth.

IMPREGNATION TREATMENT

The main purpose of the impregnation treatment of transformers is to remove the moisture and seal it out with a compound which is itself an insulator. Before the impregnation treatment was used, the same results were partially secured by drying and treating the insulating material used. This method does not give as good results as impregnation, because the treatment is confined practically to the surface of the material. With the impregnation treatment, the subsequent accumulation of moisture is largely confined to the outer surfaces, which is to be expected when the pores of the paper and cloth as well as the open spaces between are filled with the compound.

The impregnating compound can be liquified by heat, forced into the coils, and on cooling it forms into a solid mass. The wires are thereby held in position, thus preventing motion and abrasion in service, and the heat conductivity of the coil is materially increased. Tests also show that the impregnated coils show no deterioration at temperatures where plain cotton covering on conductors is injured.

The materials which can be used for impregnation are varnishes, shellacs, asphalts and resins, since they can be applied in the form of liquids which later solidify. Varnishes and shellacs contain a considerable percentage of volatile solvents which must be driven off before the material reaches the solid state. These materials are therefore seldom used to impregnate coils because of the difficulty in expelling these solvents. If the solvents could be satisfactorily expelled, the coils would be full of pores where the solvent had worked through. This leaves the asphalts and resins as the materials best suited for impregnation. Since all asphalts are soluble in oil to a certain extent, they are not satisfactory for use in oil-insulated transformers. The oil proof compounds are made from the resinous gums, compounded so as to give the desired hardness, melting point and penetrating power. The gums used come generally from Asiatic ports, and are excretions from trees belonging to the same family as the pine, from which the common rosin is secured.

In choosing insulating materials for impregnating treatment the readiness with which they absorb the compound should be considered. Cotton in the form of cloth, tape, or wire covering is easy to apply, and has good mechanical strength but does not have a high dielectric strength. For these reasons cotton fiber is particularly good as an insulating material where the impregnating treatment is to be used, serving as a supporting material for the impregnating compound, which has poor mechanical characteristics, but high dielectric strength. Varnished materials, fiber and similar substances are practically impervious, even to the most fluid of the gums.

Large spaces between wires or sections of a winding are difficult to fill. It is important in the design of the coils that a path be always left for the gums to enter such spaces, as, if they are deep within the coil, there will otherwise be no path for the gum except through

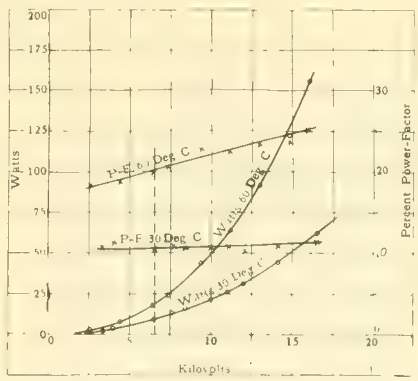

FIG. 2—DIELECTRIC LOSSES IN A 150 K.V.A., 60 CYCLE TRANSFORMER

The vertical line indicates the normal high-tension operating voltage of the transformer.

capillary spaces too small to admit a large amount. If they are near the outside, before the coil can be cooled the gum will have run out.

In the process of impregnating, the coils are first dried, either in a separate oven or in the impregnating tank. They are then placed in the tank and heated to a temperature high enough to make the gum fluid, but not high enough to injure either the gum or the insulation of the coil. A vacuum pump is then applied; usually from one to six hours for an ordinary coil provided it is thoroughly pre-heated. After the vacuum has drawn the moisture from the coils, the impregnating compound, previously heated to a liquid condition, is drawn into the tank by the vacuum. Pressure is then applied and maintained until the desired degree of impregnation is secured. With a very fluid gum, high temperature and high pressure, two hours under pressure may be sufficient, but under adverse conditions ten hours may be required. The medium furnishing the pressure must be dry before entering the tank, and the pressure generally used is from 80 to 100 pounds per square inch.

*If say forty percent was sufficient, from Fig. 4, Part VIII, in the JOURNAL for March, '18, p. 100, it is seen that this percentage of the initial value of the mechanical strength is retained with cotton heated in oil at 114 degrees C., and paper heated in oil at 125 degrees C. These temperatures are higher than those usually given, even when account is taken of the fact that the actual maximum temperature is approximately ten degrees higher than that measured by the increase of resistance method.

PROPERTIES OF INSULATING OIL

Transformer oil should have the following characteristics,*

1. High dielectric strength
2. Low viscosity
3. Freedom from deposit
4. High flash point
5. Low evaporation

The dielectric strength of clean dry oil at 25 degrees C. is usually not less than 22 000 volts when tested between one inch brass disks set 0.10 inch apart, and changes somewhat with temperature. The dielectric strength, is a maximum at a temperature between 60 and 70 degrees C. and decreases for temperatures both below and above this point. It is an important fact that the oil is at its best dielectric value at or near its normal working temperature. The resistance of oil decreases with temperature increase as does that of other insulating materials. The presence of as small an amount of water as 0.01 percent is sufficient to seriously impair the dielectric strength of the oil. The exact composition of a mixture of oil and water is a little obscure, but it seems that, with clean oil, the mixture is more or less temporary, and that the particles of water will finally settle out. In an electrostatic field the small drops are drawn together and tend to form larger ones by collision, and in transformers they will generally be attracted to the points under the greatest stress. If the oil contains fibers of foreign matter, as practically all oils do, the fibers will absorb the particles of water and thus tend to retain them in the oil. Dirt in oil may have an effect very similar to moisture and the electric field may cause the small conducting particles to bridge between the electrodes.

The presence of acid or alkali in insulating oil is not permissible, because they reduce its dielectric strength, as well as act destructively on the materials of the apparatus. An oil practically neutral is preferable, and it should contain no free sulphur which in its free form attacks copper. All petroleum oils contain sulphur compounds which, however, are not objectionable.

Since oil is usually used in transformers as a cooling as well as an insulating medium, its viscosity is important. The more sluggish the oil, the slower will be its circulation and the transfer of heat will be correspondingly slow. Heavy oil will not circulate freely through the oil ducts of the windings, with the result that there is a high temperature gradient between the oil and windings. The viscosity of oil used for transformers is ordinarily from 30.0 to 40.0 seconds Saybolt at 40 degrees C.

Deposit from oil is objectionable because it clings to the windings and fills the ducts. The cooling of the apparatus is thus affected by any deposit which occurs under normal conditions of operation. Such a deposit also renders the oil more sluggish and thus further affects its cooling action. A deposit is also an indication that chemical decomposition is taking place in the oil. Its formation is a function of the temperature and length of time the oil has been used, but at ordinary temperatures there is a tendency to form a deposit in the presence of an electric field of high intensity. Oils differ as to the temperature at which a deposit will appear. A satisfactory oil should not show a deposit or any change, except possibly a darkening of color, when operated continuously under the temperature conditions experienced during actual operation. Heating the oil gradually up to a temperature of from 200 to 230 degrees C. in one hour should not produce any other effect than a darkening of color.

Since oil in transformers may occasionally be subjected to high temperatures caused by overloads, or locally by a lightning discharge, or by corona effects, it is important that its characteristics be such as to prevent an explosion or fire even under those abnormal conditions. The usual criteria of the inflammability of oils are their flash and fire tests, usually taken with the open cup. The values for the open cup, however, differ only slightly from those taken with the closed cup, being a few degrees higher. A grade of oil found satisfactory for transformer work has a flashpoint around 125 degrees and a firepoint in the neighborhood of 150 degrees C. It is obvious that an explosive mixture is not formed with this oil until the temperature attained by an overload on the transformer is greatly in excess of normal operating temperature. When this oil is slowly heated experimentally in a closed vessel, the proportions of oil and gas spaces approximating those existing in a transformer, and an arc is formed at temperature intervals in the gaseous mixture, the lowest temperature at which an actual explosive mixture can be obtained is about 145 degrees C. However, at room temperatures it is possible to secure an explosive mixture by maintaining an arc, either below or at the oil surface. There is no danger therefore of an explosion from a lightning discharge or corona effects, unless there is an actual arc produced at the surface or beneath the oil which can evaporate enough of the oil to produce an explosive mixture, and give at least a localized temperature in excess of that of the flashpoint of the oil. Furthermore, there would be no great advantage resulting from increasing the flashpoint of the oil say 25 percent, since if the explosion occurs only when there is an arc present, it would take but a slightly longer time for the heavier oil to reach the explosive condition than it does with the lighter oil.

Light colored oils have some advantage since they permit the superficial examination of transformer connections by the aid of an incandescent lamp, without removing the apparatus from the oil.

All insulating oils evaporate slowly even at operating temperatures, and this is more pronounced in oils of relatively low viscosity. A satisfactory oil should not show undue evaporation under normal operating conditions.

*See Report of Committee on Electrical Apparatus of The National Electric Light Association for 1917.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

APRIL 1918

Dipping and Baking of Railway Motors

Dipping in varnish and then baking thoroughly fills all cracks and pores in the insulation. This greatly reduces the possibility of breakdowns, which might be caused by moisture or other conducting materials filling these cracks. Further it acts as an effective bond to prevent vibration of motor parts. Dipping and baking of comparatively new motors is an insurance against maintenance charges for rewinding, etc. It improves the insulation, fills up the pores, keeps a smooth surface on the coils and prevents vibration of motor parts.

Equipment—

1—A tank to contain the dipping solution.
2—An oven in which to bake.
3—Means of handling the apparatus.

CLEANING

Remove oil and dirt thoroughly with clean compressed air. Use a cloth dampened with benzine, where oil is excessive. To protect the polished surfaces, such as the journal and commutator face, tape with friction tape. Results can also be secured by rubbing the journal after dipping with a cloth wet with benzine.

DRYING

Heat the apparatus in an oven to 100 degrees C. so that, with the delay involved in getting it to the dipping tank, it will be at a temperature of 40 to 60 degrees C. at the time of dipping.

FIG. 1—TYPICAL DIPPING AND BAKING ROOMS

View taken from the interior of the baking room.

DIPPING

Dip in an oil-proof and moisture-proof baking and insulating varnish at approximately the following specific gravity. If the varnish is too heavy, thin with benzine.

Specific Gravity—

0.850 at 15 degrees C. temperature of solution; or
0.846 at 20 degrees C. temperature of solution; or
0.843 at 25 degrees C. temperature of solution; or
0.840 at 30 degrees C. temperature of solution.

Dip armatures in the varnish in a vertical position, commutator end down so that all windings are totally immersed. Allow to soak until all signs of bubbling cease (20 to 30 minutes).

If a tank is not available, results (though not so good) can be obtained by turning the armature at intervals of 20 to 30 minutes in a shallow pan with the varnish deep enough that the bottom of the slots will be completely immersed. If this is done, the insulated creepage surface at the end of the commutator should be treated by repeated paintings of the varnish. Turn until all the coils have been thoroughly soaked.

For direct-current machines, the field coils should be removed, dipped and baked in the same way as the armatures.

For alternating-current machines, dip the frame (the brush holders having been removed) in a vertical position, rear end down. All windings and connections should be covered. Allow it to remain in the varnish until all bubbling ceases. Do not immerse brush holder pads nor arms.

DRAINING

Drain at room temperature until all dripping ceases. The apparatus should be placed in such a position that pocketing will not occur.

BAKING

Place armatures in vertical position, commutator end down in an oven and bake at 125 degrees C. for the following time:—

Armatures below 12 inches diameter, 24 hours.
Armatures 12 inches to 30 inches diameter, 36 hours.
Armatures over 30 inches diameter, 48 hours.

If the rotor is baked in a horizontal position it should be given a one-half turn every 15 to 20 minutes during the first half of the baking period, otherwise the varnish will drain toward the lower side and throw the armature out of balance.

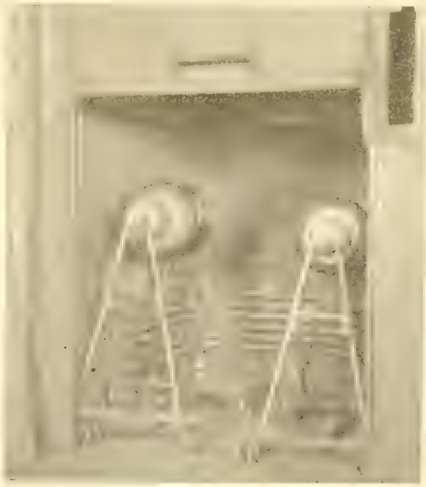

FIG. 2—STEAM HEATED OVEN

Used in a shop which takes care of 200 motors.

Place the frames in vertical position, pinion end down in the oven and bake at 125 degree C. for the same time as the corresponding size armature.

Some Don'ts to be Observed—

1—Do not use matches; do not smoke; do not use lighted torches, electric hoists or any other device that may produce sparks around the dipping tank as the varnish is inflammable.

2—If steam is used for heating, do not permit the steam to escape into the oven, thereby giving the apparatus a vapor bath. This is worse than no dipping.

3—Do not permit the temperature to exceed 130 degrees C.

4—Do not rush the baking period. A wet motor is worse than one that has not been treated.

Some Precautions to be Observed—

1—Provide for ventilation of the oven, no matter how small it is made; provide for a complete change of air in the oven once every hour; holes near the top and bottom will usually provide natural ventilation.

2—Provide uniform temperature of the air in the oven. Place thermometers at various heights in the oven to determine the temperature.

3—Turn armatures frequently, if they are baked horizontally, to prevent unbalancing.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest, information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1576—RELAY CONNECTIONS—Fig. (a) shows six series transformers, located one on each bushing of a three-phase oil switch. Are the connections correct for three-phase relay protection, and can current in each phase be read correctly with the four different positions of ammeter switch? The positions are as follows:—(1-2) (2-3) Off-no reading; (1-4) (2-3) Reads phase *A*; (1-3) (3-4) Reads phase *B*; (1-2) (3-4) Reads phase *C*.

E.G.S. JR. (TENN.)

The connections shown in Fig. (a) will give fairly good overload protection, but there is the disadvantage of not having a spare relay in case of accident. In case protection against reversal of power is desired, it will not give complete protection, as there is one case in which both relays may refuse to work. This may occur with a short-circuit between phases. Then the phase angles may be about 90 degrees, and on

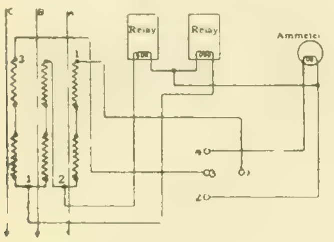

FIG. 1576(a)

account of low power-factor, the torque will be so low that the operation will not be satisfactory. The current readings for the four positions of the ammeter switch are as follows:—(1-2) (2-3) No reading; (1-4) (2-3) Phase *A* is indicated under all conditions; (1-3) (3-4) Phase *B* is indicated when load is balanced and gives an approximately correct indication with load slightly unbalanced; (1-2) (3-4) Phase *C* indicated under all conditions.

E.A.H.

1577—GENERATOR SPARKING—A 400 kw, 230 volt, compound wound, direct-current generator, the commutator of which has recently been turned, seems to operate with a very unbalanced field flux, and intense sparking at the brushes, from no load to full load, or 1600 amperes. However, with shifting of the brushes to meet load conditions, the commutation is perfect on either point (no load or full load positions.) Please advise if my theory of a shifting neutral is correct, and would a resistance across the series field help conditions?

D.F.Z. (KANS.)

Your theory of a shifting neutral is doubtless correct. Many of the early machines required a change in brush position with change in load. For theory of brush shifting see article on "Armature Reaction in Direct-Current Machines", in the JOURNAL for Jan. 1914. A resistance across the series field would not help. What is needed, is a widening of the neutral zone through a reduction of the armature cross-magnetization effect. Vari-

FIG. 1577(a)

ous schemes have been invented to accomplish this. Two of the most simple and effective ways are:—putting a very sharp bevel on the pole horn; and cutting a notch in the pole just above the shoulders, as indicated in Fig. (a). A number of old machines have been improved by the application of these methods. We recommend that the manufacturer of the machine in question be consulted before any attempt at improvement is made.

F.L.M.

1578—REACTIVE-FACTOR METER—We have a 110 volt, five ampere three-phase, 60 cycle reactive-factor meter with series resistance and transformers to check up one 500 kw and two 300 kw rotary converters. We only run the 500 kw or the two 300 kw machines at one time. Could I connect the meter in the supply main as in Fig. (a) or would I have to connect it in the converter circuits? Also would two shunt transformers do for the three circuits or would I have to have two for each circuit? Would I have to have three series transformers one for each circuit? The rotary converter circuits would be very disagreeable to change.

W.T.F. (PENNA.)

When machines are operating in parallel, the reactive-factor in the mains is not necessarily the same as in each machine; thus one machine may have lagging currents and another have lead-

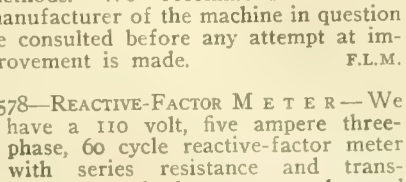

FIG. 1578(a)

ing which may cancel each other in the supply mains. A separate instrument for each converter is thus desirable. The two voltage transformers may, however, be operated from the bus as shown. One series transformer would be required for each rotary converter.

P.M.

1579—RECONNECTING INDUCTION MOTORS—(a) We have a three horse-power, two-phase, 60 cycle, 110 volt, 1200 r.p.m. induction motor, having 48 slots and 48 coils. The coils are made up of No. 17 B & S wire, two coils of 14 turns, each tied in parallel. This being a two layer winding makes 28 conductors per slot. $48 \div 2 = 24$, $24 \times 28 = 672$ conductors per phase. This motor's insulation broke down and had to be rewound and we desire to make it three-phase, four pole, 1800 r.p.m. and 220 volts. We ordered the coils from the manufacturer and they sent us 24 coils made up of No. 16 B & S with 32 turns. How was this calculated? (b) If a four pole induction motor with a lap winding was rewound and connected with a wave winding, could the voltage be doubled on this same motor? Does this hold good on any number of poles on an induction motor the same as it does on direct-current in regard to voltage with these two styles of winding. (c) If a six pole induction motor wound for 440 volts and connected series star was to be reconnected for 220 volts with a two parallel star grouping would it make any difference in the paralleling if one was to take the three north poles, that is, if we start with the north and skip the south, pass through the north and skip the next south and then pass through the north and connect to the star, and then do same with the three south poles. Or would it be better to start with the north pole, pass through the south and then a north, making a north, south, north in one side of the parallel and the other side would have south, north and south?

O.B.E. (WASH.)

(a) If the motor be thought of as an alternating-current generator, having practically the same total magnetic field in the air-gap at all times and this field as rotating at 1200 r.p.m. in one case and 1800 r.p.m. in the other case, it is evident that, cutting the same number of conductors, it would generate 50 percent more voltage at 1800 r.p.m. as at 1200 r.p.m. However, this generated voltage or counter e.m.f. need only be equal to the line voltage in either case and if the same line voltage be assumed it is evident that only two-thirds as many conductors will be required at 1800 r.p.m. as are needed at 1200 r.p.m. One essential fact has been omitted in giving the data, viz:—the pitch or throw of the coils or the number of slots between the two sides of the coil. This is necessary as it affects the generated voltage differently in the two cases. This is called "chord factor" and is measured by the sine of half the electrical angle spanned by the coil if the distance from the center of north pole to the center of south pole be called 180 degrees. (See article on "Reconnecting Induction Motors" by Mr. A. M. Dudley, in the JOURNAL for Feb. '16). Assuming that each coil is exactly 180 electrical degrees or lies in slots one and nine, makes the chord factor equal

one, in the case of the six pole connection or 0.866 for the pole. This means that $\frac{1}{0.866}$ or 1.15 times as many conductors will be required on the four pole connection due to this feature alone. There are then, the following factors to be considered. First, in changing from 110 to 220 volts, twice as many conductors will be required. Second, in changing from two phase to three phase, 0.8 as many conductors will be required. Third, in changing from 1200 to 1800 r.p.m., two-thirds as many conductors will be required, as explained above. Fourth, there will be 1.15 times as many conductors required on account of the "chording" or throw of the coils. Since there were a total of $672 \times 2 = 1344$ conductors in the first place, there would be required $1344 \times 2 \times 0.8 \times 0.66 \times 1.15 = 1635$ total conductors for four poles or $1635 \div 3 = 545$ conductors per phase, which approximates the 512 conductors furnished by the manufacturer within six percent and was probably the nearest stock coil available. (b) No, this is not the case with an induction motor. The connection of the pole phase groups reduces the lap winding to the same basis as a wave winding and the conductors are equally effective in both cases. There is no factor of two to one as in the direct-current. (c) No, it would not make any difference in what order the poles were passed through as long as they were passed through in the right direction. The article in the February '16 JOURNAL discusses this and similar problems.

A.M.D.

1580—RELAY REACTANCE—Referring to a paper by Torchio on "Relays for High-Tension Lines" of March 9th, 1917, before the A.I.E.E., a number of the meter and relay diagrams show a reactance connected in parallel with the I.T.L. relay coil; what is the function of this reactance and the theory of its operation?

J.M. (CAL.)

The reactance which is placed in shunt with the relay is an iron core reactor. The object of this reactance is to limit the excessive current which can pass through the relay due to the saturating characteristic of the reactor. This prevents chattering of the relay and, in addition, gives the relay a more definite time setting, which results in a time characteristic curve very much more satisfactory for proper selectivity on series connections.

P.T.

1581—BATTERY CHARGING—Why is it that when charging batteries whose voltage equals nine-tenths of the voltage of the generator I am unable to use the series field winding? It will run about twenty seconds, then will overload and kill the engine.

J.B.R. (MONT.)

With the limited information given, the only conclusion we can reach is that the generator is probably too much over-compounded. As a result of this, when the charging of the battery is first commenced, the current flowing will be of a certain value. However, as this charging progresses, the temperature of the battery is increased more rapidly than the counter e.m.f. which results in a lower internal resistance of the battery, thereby allowing the generator current through the battery to increase. This increase in current increases the generator terminal voltage due to the compounding of the series coil. This cycle continues until the current flowing through the battery and the load on the generator are greater than the gas engine can carry, resulting in killing the engine.

A.M.C.

1582—SYNCHRONOUS MOTOR—GENERATOR SET—We have a 25 cycle, three-phase, 2300 volt, 300 r.p.m. synchronous motor direct connected to a two-phase, 60 cycle generator. Is it permissible to restore normal voltage to the motor, should the set be in parallel operation and the motor switch open; the generator switch being closed, and the unit operating as a condenser, the field circuits of both motor and generator being intact? (b) With the same condition as above, is it permissible to restore the motor field, should it open accidentally or otherwise, the motor supply switch being closed, and the motor operating as an induction motor? (c) With two or more sets in parallel operation, what would be the effect, should the field circuit of the generator open and be immediately closed?

G.W.G. (PENNA.)

(a) In answering this question, it is necessary to assume certain conditions; it may be assumed that the frequency changer set was previously operating in parallel on both ends with one or more other sets, and that the line switch of the 25 cycle motor was then opened and the 60 cycle generator allowed to act as a condenser. The other assumption is that the 60 cycle machine was started from rest, by the self-starting method or by a separate driving motor, and was then operated as a condenser without any attention having been paid to the 25 cycle end of the set. Under the conditions of this latter assumption, it is possible that the 60 cycle machine has been synchronized with its bus in such a position that the relation of the 25 cycle machine to its bus is not correct for paralleling. If this be the case, the rotor must first be brought to the correct position in the usual manner. (See article on "Parallel Operation of Frequency Changer Sets", by Mr. F. D. Newbury in the JOURNAL for Nov. '16, p. 542). When the synchroscope shows that the phase difference between the voltage of the 25 cycle machine and the voltage of the 25 cycle bus has been reduced to a minimum, the conditions are the same as those of the first assumption—that is, the same as if the 25 cycle machine had previously been paralleled and had later been disconnected without the set having been shut down. Under these conditions the phase difference between the 25 cycle voltages is due to the load which is being carried by the other set or sets, which tie together the 25 cycle and 60 cycle systems. With a heavy load on these other sets there are fairly large phase displacements in both the motors and the generators, which add together and which manifest themselves in a total phase displacement between the 25 cycle bus voltage and the voltage of the unloaded machine which is to be paralleled with it. The heavier the load on the other sets, the greater will be this phase displacement. In any case, however, the phase difference should not be sufficient to cause trouble when the switch is closed. In fact, this phase difference always exists when a loaded set and an unloaded set are to be paralleled. (b) It is permissible to close the motor field circuit while the machine is operating as an induction motor, although fairly heavy rush of current can be expected. The value of this current can be reduced by lowering the voltage applied to the motor before the field circuit is closed. It must be understood that the accidental opening of the shunt field circuit does not necessarily imply that the motor has fallen out of step. If the set be operating in parallel with other sets, it will simply drop part of its load, but will continue to operate at synchronous speed. Closing the field circuit will cause it to pick up its load. (c) When the set is operating in parallel with one or more sets, the opening of the generator field circuit causes the energy load of that set to be reduced, although the k.v.a. of the generator may be increased. When the field circuit is closed normal conditions are restored.

Q.G.

1583—BALANCING GAS ENGINE FLYWHEEL—I have a single cylinder, single acting, two cycle, vertical gas engine having two flywheels placed outside of the main bearings and equidistant from the crank. It has a throttling governor, thereby causing some explosive action to take place every revolution. I desire to balance this engine by placing counterbalance weights on the flywheels. I have tried making the moment of these weights equal to three-fourths of the moment of the combined weight of the piston, wrist pin, connecting rod, and crank pin, as recommended by a handbook. This however, did not produce very satisfactory results, as the engine vibrates considerably. Please give me the proper formula for figuring these weights.

H.W.A. (MO.)

If there are no counterbalances inside the crank case, which is very unlikely, the above formula is fairly good. It gives as good vertical balance as possible. The nature of the support often makes horizontal balance more important. It is secured by making the moment equal to that of the crank pin + cheek + three-fourths of the connecting rod.

A.T.K.

1584—HEATING OF SOLDERED JOINT—Considering a soldered joint as shown in Fig. (a) of 1600 ampere capacity on a 200 ampere per square inch rating, under a short-circuit conditions of say 60 000 ampere for 0.2 second. Will the solder melt? Please give formula to compute the time required, or the value that the current must attain, be-

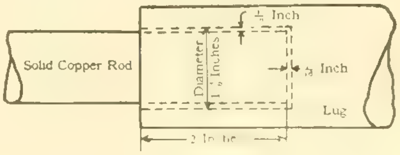

FIG. 1584(a)

fore solder will melt. Assuming solder does melt under any given condition, will it, on solidifying, make any change in the ampere per square inch rating of the joint, i.e., what is considered good practice in such an instance?

C.F.P. (ONTARIO)

Assume dimensions as shown in Fig. (a) and let $H = 0.24\ I^2RT$ in calories. I = current flowing in amperes. R =

resistance of material in ohms. T = time in seconds.

$$R = [illegible]$$

Where A = area in sq. cms. = $\left(\frac{1600}{200}\right) \times 6.45$ = 51.6 sq. cms. l = length in cms. = 0.159. ρ = microhms per cu. cm. = 18.75 for solder, R = resistance in ohms. One microhm = 0.000001 ohm. Let S = specific heat of solder = 0.041 approximately and G = weight of solder in grams = volume in cubic inches × 148.4. Then temperature rise in degrees, C =

[illegible]

Volume = [illegible]

$\pi 1.375$ [illegible]

Therefore G = 88 grams. In the problem given, I = 60 000 and T = 0.2 second. Then Degrees C. rise =

[illegible]

As the melting point of solder is approximately 188 degrees C. the solder will not melt with a short-circuit of 60 000 amperes for 0.2 second. To obtain the length of time required to melt the solder—Assume an initial temperature of 23 degrees C.

$$T = \frac{\text{Degrees rise} \times S \times G \times A}{0.24 I^2 \times \rho \times l \times 0.000001} = \frac{165 \times 0.041 \times 88 \times 51.6}{0.24 \times 60\,000^2 \times 18.75 \times 0.159 \times 0.000001}$$
$$= 12 \text{ seconds}$$

As most protective apparatus in selective systems is set for a maximum time of short-circuit of approximately two to four seconds it is seen that the solder would not melt in practice. The above is entirely theoretical and does not assume any heat transfer from the solder which if considered would make the temperature still less for a given time of passing of a given current. If the solder should melt, the position of the terminal would determine whether or not the current capacity of the joint had been decreased after the solder had solidified. If the position is such that the solder all remains in the lug, the amperes per square inch rating of the joint would not be changed after solidification of the solder. S.G.L.

1585—PARALLEL OPERATION OF ALTERNATORS—We are at present operating twelve 60 cycle, 2300 volt alternators in parallel, direct-connected to Diesel oil engines. We desire to increase the output of the plant. Having a steam turbine on hand, it was thought possible to parallel it with the Diesel plant. Can this be done with a varying load? We are operating an electric railway system, in addition to supplying power to motors on hydraulic mining, which cause a very fluctuating load. We have tried in the past to synchronize our other plant operating reciprocating steam engines with this Diesel plant but when the load came on the steam plant would try to take it all and would knock off the board. The inherent nature of the Diesel engine is to be sluggish in handling these fluctuating loads paralleled with a prime mover with closer regulation, and I contend that we would have still greater trouble trying to keep this turbogenerator on the board than we did with the reciprocating engines, inasmuch as the turbine would be more sensitive to trying to run away with the load. H.P.B. (FLA.)

Diesel engine-driven and steam turbine-driven units will operate satisfactorily in parallel, if the speed regulation of the steam turbine from no load to full load is made the same as that of the Diesel engine. To accomplish this may mean cutting off one or two turns from the governor spring. S.L.H.

1586—440 VOLT VS. 220 VOLT DISTRIBUTION SYSTEMS—What are the objections to the use of 440 volts, three phase, 60 cycles in a factory system over a 220 volt system? Is the voltage considered too high? Are these systems being replaced by 220 volts? A.H.A. (ILL.)

The use of 220 volts is more general than the higher value as evidenced by the sale of industrial motors. Probably 80 percent of these are built for 220 volt circuits. 440 volts would be comparable to a 500 volts direct-current, which is rarely used in industrial plants. The higher voltage has the advantage from a distribution view point but is not generally used due to objection to the higher potential. F.C.H.

1587—MAXIMUM CABLE SIZES—What is the maximum size of three-conductor lead covered cable advisable for use in a 2300 volt underground distributing system. 300 000 circ. mils has been suggested as an upper limit. M.J.I. (D.C.)

The size of cable is usually governed by local conditions rather than by general technical considerations. For 60 cycle installations the size of three-conductor cable is economically limited to about 300 000 circ. mils or sometimes as large as about 500 000 circ. mils. The additional limitation at 60 cycles is due to the reactance becoming of importance in the larger sizes and to increase of skin effect. Both of these factors are of small importance with the smaller size mentioned, and are of appreciable importance in the case of the larger size. Under any condition, the amount of copper required for a given carrying capacity is considerably less with a greater number of smaller cross-section cables. For instance, two cables of 250 000 circ. mils each will carry from 10 to 30 percent more current than will one 500 000 circ. mil cable under the same conditions of installation. The conditions of installation will also govern the relative carrying capacities. The larger increase is under conditions favorable to carrying capacity, that is where there is little rise in temperature of the surroundings, due to the heat of the cable. Cables as large or larger than 750 000 circ. mils, three conductor, have been made, but a very small percentage of the three conductor cable manufactured is of larger size than 250 000 to 350 000 circ. mils. This latter data illustrates the present general commercial result of the various factors which affect the size of cable actually used. Another example is that one very large operating company does not use cable larger than 0000, three conductor cables even in very large duct systems. R.W.A.

1588—ROTARY CONVERTER—I have a one kw, four-pole, compound wound, 110 volt, 750 r.p.m. direct-current generator for charging storage batteries. It is driven from an engine. This generator has only two brushes. Can I install two slip rings and connect them at opposite joints on the commutator and operate this machine as a single-phase rotary converter. Of course I understand that it will increase the speed to about 1800 r.p.m. Now will the increase in voltage due to the increase in speed, effect the armature? Also at what voltage (approximately) should the supply current be applied? The commutator of the generator is unusually large and has exceptionally heavy segments so I do not think I will have any trouble from that source. J.B.R. (MONT.)

It will probable be impracticable to operate this machine as a 60 cycle converter. The average direct-current generator of this size and capacity cannot be operated safely at 1800 r.p.m. From a purely electrical standpoint, it would be possible to tap the armature at two diametrically opposite points as suggested and operate the machine as a single phase converter, though the operation might not be satisfactory. A single-phase converter is none too stable at best, and when operated without a damper winding its instability is more pronounced. Moreover, in order to keep the iron losses within reasonable limits at the higher speed, it would be necessary to reduce the flux density and at 1800 r.p.m., the direct-current voltage would be 132 which would require about 95 volts on the slip rings. The permissible current output would be reduced considerably, probably to 60 or 70 percent of its former value, on account of the high copper loss which occurs in the armature of a single-phase converter. One other drawback is that the machine could not be started from the alternating-current side, but would have to be started from the direct-current side, if direct-current power were available, or by some external means. The main objection to its operation as a 60 cycle converter, however, is the necessary speed of 1800 r.p.m. which is probably unsafe for the machine. Q.G.

1589—ROTARY CONVERTERS—(a) What is the relative output rating of (1) a direct-current generator (2) a three-phase converter (3) a six-phase converter? Assuming the same frame size and speed in all cases. (b) Is it possible to get a voltage range of 70, 100 and 140 percent volts on a booster converter? That is if the direct-current voltage with the alternating-current rotor not excited is 100, can 70 and 140 volts direct-current be obtained by exciting the alternating-current end to buck and boost the direct-current rotor? If this range in voltage cannot be obtained, then what are the percentage limits? (c) How does the voltage range desired on a booster converter influence the cost? Assuming the case of a direct-

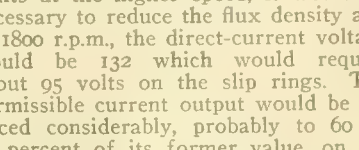

FIG. 1589 (a)

current voltage range of 70, 100 and 140 volts, what would be the comparative cost of such a machine compared with a direct-current generator of equal speed and output? (d) Is it necessary to use two separate rotors on a booster converter Would it not be equally as effective to use a common rotor excited by two sets of magnets, as shown in Fig. (a)?

L.T.W. (MO.)

(a) Basing the relative output of a direct-current generator and rotary converter on the heating of the armature and assuming 100 percent power-factor operation of converter, the direct-current generator would have approximately 75 percent of the capacity obtainable as a three-phase converter, and 52 percent of the capacity obtainable as a six-phase converter. (b) Due to the increased armature heating, as well as the effect on commutation of changed armature reaction, it is not customary to design booster converters for a larger range than 15 percent voltage variation either side of the normal voltage obtained with a given transformer tap. The larger range can be obtained by additional transformer taps, although special provision is necessary in the design of such a unit to take care of the field excitation margin, and unusual iron densities at the extreme (boost) voltage condition, as well as the commutation characteristics. (c) No fixed ratio can be given for comparing costs of straight converters and booster converters. In general, it might be assumed that twice the percentage of voltage range of the booster machine added to the cost of the straight converter would be an approximate value. For instance, if a straight converter of given characteristics cost $1000, a booster converter of similar characteristics good for 10 percent voltage variation would cost, roughly, 20 percent more, or $1200. The comparison of converter and direct-current generator costs varies so widely, due to characteristics, type of service, etc., that no approximate cost figure could be given. (d) Separate rotors are essential in a booster converter. The scheme shown in Fig. (a), covering a single rotor with two separate fields, would vary only the power-factor without affecting the voltage of the machine. The reason for this may be better understood by considering that in a straight rotary converter a fixed ratio exists between the alternating-current and the direct-current voltages, and that no change in field ampere-turns can alter this ratio. In this particular instance it may be considered that the two fields shown side by side are superimposed on each other, forming a definite flux density in the air-gap due to their combined action. As no change in field ampere-turns can vary this air-gap density, a common rotor, therefore, excited by two sets of magnets would not be effective in changing the voltage, because any change in the excitation of the regulating poles would simply be neutralized by an opposite change in the magnetizing effect of the armature winding. The alternating-current voltage can be changed by changing the booster excitation with a separate booster only, because the booster armature is connected in series with the circuit, and there is no opportunity for the armature magnetizing effect to change when the excitation is changed.

R.H.N.

ENGINEERING NOTES

Aim—To connect theory and practice

Star-Delta Starting of Small Induction Motors

Small induction motors can be started by direct connection to full-line potential. With motors of larger size, where the starting current under such condition is objectionable, and where an autostarter is undesirable, the motor can be started

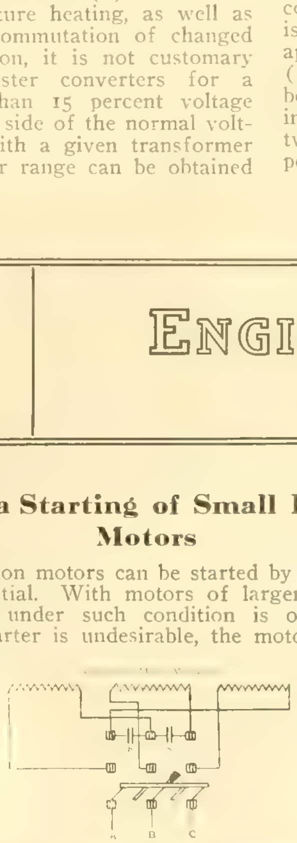

FIG. 1—CONNECTION DIAGRAM

with the effect of a low voltage by bringing out six leads from the windings to a special star-delta starting switch. The connections for such a starting scheme are shown in Fig. 1 and a suitable switch for this method of starting is shown in Fig. 2. The initial position gives a star connection, while the final or

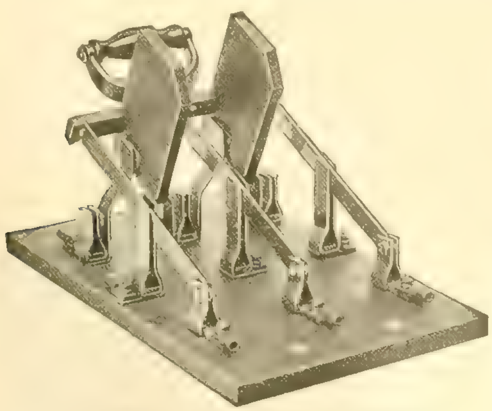

FIG. 2—STAR-DELTA STARTING SWITCH

running connection is in delta. This has the effect of putting on the motor at start about 58 percent of full voltage and consequently reducing the starting torque to $\left(\frac{1}{\sqrt{3}}\right)^2$ or one third its normal value on full voltage. For this reason the usefulness of this scheme is limited to cases where this low starting torque is sufficient to that of the load. Where a higher starting torque is required the usual autotransformer starter should be used.

Viscosity

The viscosity of an oil is a measure of its fluidity. In most cases it is desirable to have the viscosity as low as possible without introducing other undesirable characteristics. For example, in a bearing oil low viscosity means low internal friction and consequently a low degree of heating of the bearing. As is so frequently the case in engineering problems, however, there is a conflicting tendency. The oil must have sufficient body or weight to keep the bearing surfaces apart; and a heavy oil has a high viscosity, that is it does not flow readily. In practically all cases therefore a compromise must be effected. The range of oil which is best suited to any particular purpose is frequently not very wide, and in any case uniformity of product is always desirable—hence the necessity for some means of accurately measuring the relative viscosity of different oils.

The viscosity of oil is usually measured in the United States by means of the Saybolt viscosimeter, a form of which is illustrated in Fig. 1. This instrument is based on the principle that the relative fluidity or viscosity of oil samples is indicated by the time required for a standard quantity to pass through a standard small orifice under equal pressure and temperature conditions. The essential element of this instrument is a tube having a restricted orifice as shown in Fig. 2 through which the oil is required to pass. The viscosity of an oil, as expressed in seconds represents the time required for 60 cubic centimeters to pass through the standard orifice at standard temperature.

The viscosity of any oil varies greatly with its temperature, as is shown in Fig. 3 for a typical sample of modern, high-grade transformer oil. Hence it is necessary that the viscosity be measured at a specified temperature, which in general should correspond as closely as possible to the temperature at which it is to be used. This in turn requires a means for maintaining

the sample of oil at a constant predetermined temperature, which in the standard Saybolt viscosimeter is accomplished by immersing the tube in an oil bath which can be artificially heated, usually for convenience by means of an electric heater. The temperature generally adopted for viscosity tests on lubricating or transformer oils is 40 degrees C.

FIG. 1—STANDARD SAYBOLT UNIVERSAL VISCOSIMETER

For testing cylinder, valve and similar oils with the bath at 212 degrees F. and the oil at 210 degrees F.; or lighter oils at any temperature up to 212 degrees F. The instrument as shown is equipped with electric heating element, with gas heating burner and with U-tube for steam heating.*

*Cut furnished by Eimer & Amend.

In using the Saybolt viscosimeter the bottom of the tube shown in Fig. 2 is first corked and the upper part of the tube is then filled with the oil. The air pressure in the lower part prevents the oil from passing through the orifice. The oil bath and the oil sample are then brought to the standard temperature as measured by thermometers. When the correct temperature has been attained the cork is withdrawn by suitable means, such as the loop of wire shown hanging in Fig. 1, and the time required for exactly 60 cubic centimeters of the oil to flow into the flask is measured with a stop watch.

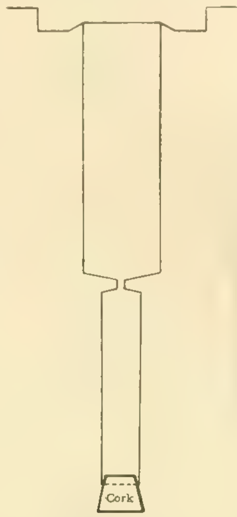

FIG. 2—CROSS-SECTION THROUGH VISCOSIMETER MEASURING TUBE

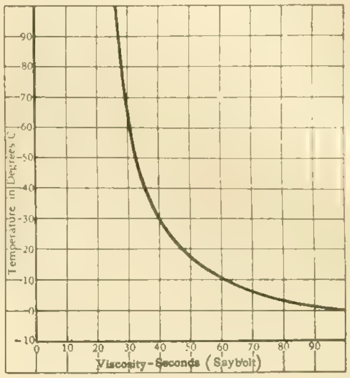

FIG. 3—VARIATION OF VISCOSITY WITH TEMPERATURE

DEAN HARVEY

THE ELECTRIC JOURNAL

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The Flash Suppressor

Any device or combination of devices which will prevent the flashing-over of direct-current railway generators when subjected to severe short-circuits may truly be considered a marked advancement in the electrical art. For years, engineers have striven to obtain this result, but without success, until finally it has become generally considered that all railway generators will flash over if subjected to a severe enough short-circuit.

Various improvements have been made from time to time in the inherent commutation characteristics of direct-current generators, the most notable of which were the introduction of commutating poles and the neutralization of the effect of the armature current on the main field by the introduction of conductors connected in series with the armature and located in the main pole faces. Arc barriers on the commutators have also proved of value, but up until the present time no railway equipments could be said to be immune from flashing.

As higher voltages have come into use, the dangers to attendants and to apparatus due to flashing have increased greatly, and the absolute necessity of some device which will truly prevent flashing has become quite evident. All existing devices have been in the nature of auxiliaries, operating *externally*, and tending to reduce the intensity and damage of the short-circuit. The flash suppressor, described in this issue of the JOURNAL by Messrs. Storer and Hague, may be said to operate *internally*, not *externally*. It suppresses instantly the underlying causes of flashing, namely, high brush currents and high voltages between adjacent commutator bars. These factors cannot exist, or be maintained simultaneously with an internal short-circuit, such as is produced by the flash suppressor described. Hence, it can be said that this arc suppressor attacks, for the first time, the source of flashing, and therein lies the assurance that the "Suppressor will suppress."

DAVID HALL

The Mutual Forces between Reactance Coils

The virtue in a reactance coil, when used to set a safe limit to the flow of current, lies in its magnetic field. When trouble comes and a large part of the impedance of the circuit is cut out, as at times of short-circuit, this field comes to the rescue with a counter e.m.f. which chokes back the tremendous current which would otherwise flow. This is the commendable side of the behaviour of a current-limiting reactor.

If this magnetic field, however, happens to come within the range of influence of another field of the same sort, both reactors develop a tendency to move either toward each other or away from each other depending upon how they are connected in the circuit. This tendency can become great enough to have serious results when a short-circuit occurs, if the coils are located too close together. So it behooves the user of current-limiting reactors to know something about the magnitude of this tendency, which is one of the less commendable attributes of the magnetic field.

The mutual forces between coils depend upon the current flow in the coils and the number of lines of force from one coil which thread through the other coil, i. e. the mutual inductance. The magnitudes of the forces can, therefore, be calculated and expressed in pounds. Mr. H. B. Dwight has developed, in this issue of the JOURNAL, a very interesting set of formulæ to calculate the mutual forces between coils when installed one above another with a common axis.

In the example given involving the forces of repulsion acting on the end coils of a group of three, the average force on each end coil is approximately 19 pounds with a current of 500 amperes. Assuming the coils to be connected in an 11 000 volt, three-phase, 25 cycle system large enough to ignore the impedance of the generators themselves, the current through the coils with a complete three-phase short-circuit would be 9000 amperes and the average force of repulsion between the end coils would become approximately 6300 pounds. In an actual installation, the forces would be less because the coils would be spaced further apart.

A very interesting feature of Mr. Dwight's article is the close agreement between the calculations and tests actually made on a coil.

W. M. DANN

What Would Watt Think?

As pointed out by Mr. R. N. Ehrhart in this issue of the JOURNAL, James Watt's first engine used steam at very little if any above atmospheric pressure. In these days of coal conservation, this fact is well worth remembering. The sky lines of our industrial centers are pierced by numerous jets of white vapor which represent wastage of steam at least as good as was available to Watt in his initial experiments. It is doubtful whether this famous engineer would have any great degree of admiration for some of our "improvements" over his early designs.

Of course it is impracticable to apply condensers to steam locomotives or to all stationery plants. Nevertheless, the steam exhausted at atmospheric pressure contains as much energy which can be made available as is developed by it in expanding to atmospheric pressure. Even an elementary consideration of the principles involved emphasizes the desirability of burning coal for power purposes in the largest and most efficient generating stations only. The sooner this result can be generally brought about, the sooner can coal conservation become truly effective.

CHAS. R. RIKER

The Flash Suppressor

N. W. STORER and F. T. HAGUE

THE GREATEST DIFFICULTIES connected with supplying direct current power for railway purposes have always been in the commutation of the generators or rotary converters during the short-circuits which are apparently inherent to this class of service, and in the circuit breakers for interrupting the current. Time and experience have worked wonders in overcoming these difficulties with the standard 600 volt railways, and the modern generator with compensating winding and commutating poles is a remarkably rugged and serviceable machine. It will withstand high momentary overloads without injury and nothing but the most abnormal short-circuit on the line will cause what is known as a flashover. The standard switchboard circuit breaker has kept pace with the generator in effectiveness.

The increasing use of direct current at higher and higher voltages has called attention to the fact that the problem of commutation on excessive overloads is still with us. It increases in magnitude as the voltage rises, for two very good reasons;—first, it is difficult, if not impossible, to obtain as good commutation as with the lower voltages, and second, a short-circuit on the line usually gives a much greater overload, because the line resistance, especially near the station, is not increased in proportion to the voltage. The result has been that in practically all the heavy installations from 1200 volts up, flashing has been much more prevalent than with the average 600 volt station, while in stations for 2400 and 3000 volts, it has been so serious as to threaten the success of the entire installation. Fortunately, it has been possible by some means to alleviate the trouble either by tapping in feeders at a distance from the substation, which introduces a permanent resistance in the circuit, or by the use of other even more drastic remedies.

A number of important features enter into a consideration of this problem, prominent among which are the nature and cause of flashing and the time element involved. Flashing is the phenomenon ensuing when the commutator becomes enveloped and short-circuited by a conducting flame reaching from brush to brush or from brush to ground. It is primarily the result of the machine's effort to free itself from delivering a load beyond its limiting capacity, and may be initiated by a number of causes.

The voltage and current relations of a generator under extreme overload conditions, are shown in Figs. 1, 2 and 3 for two typical cases on a non-compensated commutating-pole generator. In Test *1* Fig. 1, the machine was short-circuited through a predetermined resistance of sufficient value to give five times full-load current. This was approximately the maximum current this machine could deliver and not flash over. The current rises to its maximum value in approximately 0.01 second while the time required for the ordinary circuit breaker to begin to act is about 0.07 seconds. The voltage shows the characteristic initial dip of the same duration as the increase of current. The voltage between 0.01 and 0.07 seconds represents the normal terminal voltage of the machine when delivering this large current, and its departure from the normal value may be attributed largely to field distortion. The normal voltage is re-established after a series of oscillations, which are not entirely reflected in the current wave because they are partly due to the main field flux re-establishing itself, and partly to the unstable arc in the circuit breaker.

In test *2*, Figs. 2 and 3, the resistance was lowered sufficiently to cause the machine to flash over. In this case the oscillograph reads only the current in the external circuit, and does not read the current which flashes between brush arms. The field distortion and drop in voltage are more pronounced because they are caused by the total current which is in excess of the value shown. The flashover probably started at about

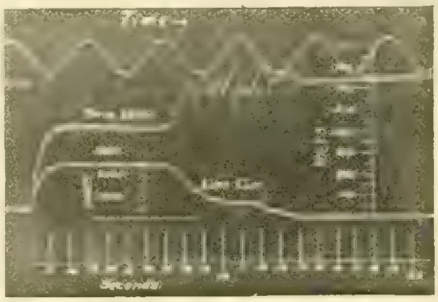


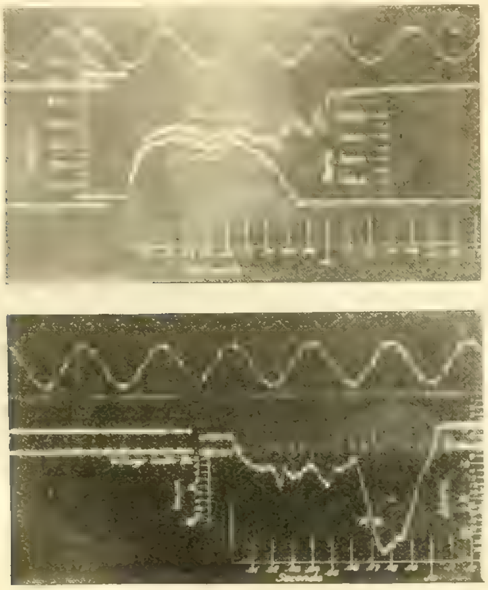
FIG. 1—MAXIMUM SHORT-CIRCUIT POSSIBLE WITHOUT FLASHOVER

0.025 seconds, and developed into a complete flashover at 0.065 seconds, as the line current beyond this time shows a gradual decrease due to the current taking the lower resistance path through the arc. The line current is interrupted before the flash is ended, so that normal voltage is not re-established until the flashing ceased.

While flashing may be started by a number of causes, the two principal ones are high-voltage between commutator bars, regardless of its origin, and bad commutation due to excessive overloads. The maximum voltage between adjacent commutator bars under load conditions and the voltage per unit circumference of commutator surface are criterions of the probability of flashing. Line voltage exists across the commutator face between adjacent brush arms, and this voltage is split up into as many sections as there are commutator bars per pole, being distributed between the bars in proportion to the voltages generated by the coils connected to them. The mechanical separation between adjacent bars is usually 30 to 40 mils, so that it might be inferred from the sparking voltage required to jump this distance in air that potentials of

several hundred volts might be safe between adjacent bars. However, experience has proven that approximately thirty volts is the maximum that is safe for large machines. Compensating-pole face windings, by eliminating load distortions, are very beneficial in preventing excessive voltages between adjacent bars, and make their use imperative on generating equipments where unusual voltages and overload conditions are encountered.

Current is delivered from a direct-current generator to its line through the process of commutation. Successful commutation requires that each armature coil must have its current completely reversed each time the bars, to which it is connected, pass under the brushes. The reversal of current in an inductive armature coil necessarily involves a change of magnetic energy in the coil, and unless this energy change is accomplished while the coil is still short-circuited by the carbon brush it will be evident by an arc as the coil breakes contact with the brush. It is the function of the commutating poles to accomplish this energy change in the commutating coils, and to the extent to which they fail to reverse the load current in the allotted time sparking results. For perfect operation, commutating pole strength must increase directly with the load current and this requires that the poles be carefully proportioned magnetically in order to use the space that is available for them to the fullest advantage. Commutating poles of tapered body sections represent the maximum which the designer can do to improve the commutating pole's efficiency at very high loads.



FIGS. 2 AND 3—LINE CURRENT, LINE VOLTAGE FIELD CURRENT AND VOLTAGE UNDER A BRUSH

During a short-circuit which caused a flashover.

On overloads so severe that the brushes glow and vaporize and the commutating poles can no longer perfectly reverse the load current in the commutating coils, an incipient arc may shoot out conducting vapor and bridge across a number of commutator bars having a high total difference of potential. In this case, the arc so started between bars may be successively carried around the commutator by mechanical rotation, resulting in a short-circuit between brush arms, or it may blow itself out in an explosive puff, or, on grounded circuit machines, it may even find a shorter path to the opposite polarity by jumping through the envelope of conducting carbon and copper vapor to bearing pedestals or frames. At the time of flashover, an enormous amount of energy is concentrated in a very small space, resulting in burning of brushholders, roughening the commutator surface, marking of pedestals, and injury to bearings, not to mention the hazard to attendants who may be near.

There are two time factors to be considered in any study of flashing. First, the time required in case of short-circuit for the current to reach a value that will cause flashing. This depends on the impedance of the entire circuit, including machine and line. Second, the frequency of the generator, since this determines the time required for a bar to pass from one brush to another. For example, a commutator bar on a 25 cycle generator will pass from one brush to another in 0.020 second, while a 60 cycle machine allows only 0.0083 second. In the worst case, that of a short-circuit at the terminals of the generator, the time required for the current to build up to the flashing value depends on the impedance of the machine alone, so that the ultimate time factors are both determined by the design of the generator.

Usually, it requires from 0.003 to 0.006 second for the current to reach a flashing value; this, of course, being dependent both on the overload capacity of the machine and on its impedance. Inasmuch as the time of one alternation is usually several times this amount, the time interval from the beginning of a short-circuit until flashing takes place depends more on the latter characteristic than on the former. It is, of course, true that the higher the armature frequency the less the distance between brush-holders usually is, and this increases still more the liability to flash, since a slight puff may reach from one brushholder to another in far less time than it takes for the commutator bar to travel between brushes. To prevent this, barriers are sometimes resorted to which make it difficult for the arc to travel directly from one brushholder to the other, or from brushholder to ground. These have been found to be of very material assistance, where high-speed circuit breakers are used, although they are essentially a makeshift, since they only reduce the effects instead of removing the cause.

It is obvious that, if the circuit could always be opened before the current could reach the flashing value, it would practically prevent flashing caused by overloading. This, however, has thus far been out of the question for heavy currents and high voltages, since not only must the circuit breaker be open, but the arc must be broken in the few thousandths of a second required for the current to build up to its maximum safe value. It has been possible, however, due

to the greater time allowed an account of the usual low armature frequency of high voltage generators, to open the circuit or to insert a limiting resistance in it before the machine can flash from brush to brush, except under the most severe conditions. This requires, as may be readily understood, a circuit breaker with a rather complicated mechanism and extremely powerful springs under heavy pressure. Such a circuit breaker must be able to carry the normal current with the usual temperature rise and must be able to open the high-voltage circuit or insert the limiting resistance. Such a circuit breaker will be subject to relatively rapid deterioration and, unless kept at the maximum point of efficiency, will slow up its speed; then if it fails to open the circuit before the flash starts, it will be too late to stop it.

A device for preventing flashing, which differs radically in its theory of operation from all circuit opening or reactance inserting devices, has recently been successfully developed. It is a device which functions to protect the machine from injuring itself when its current output exceeds a predetermined value. It is known as the "flash suppressor" and is being installed by the Westinghouse Company in the 3000 volt substations of the C. M. & St. P. Railway. The flash suppressor directly attacks the cause of flashing and directly suppresses it while all other schemes, so far proposed, have merely attempted to minimize the liability of flashing or to mitigate its effect more or less completely. The flash suppressor consists of a set of small contactors, arranged to short-circuit the armature windings of the direct-current generator through three collector rings, connected in three-phase relation. This device is actuated and tripped in a manner similar to that of the circuit breaker, but with this difference—the contacts, which carry current only momentarily when the device operates, are very small and light, and have normally but a short distance to travel; it differs also, in the fact that this device closes a circuit while a circuit breaker opens one and must, therefore, quench the arc before it can completely rupture the circuit.

To secure operation equally as quick as that of a high speed circuit breaker, only a relatively simple mechanism is required, and it is not difficult to secure a much higher speed without complication. The contactor can easily be made to close in from 0.006 to 0.008 of a second, which is amply fast to prevent a flash from spreading on any but the higher frequency machines.

The flash suppressor performs a double function,—first, closing a short-circuit on the collector rings, which simultaneously reduces the voltage between commutator bars practically to zero. If the voltage per coil were the same throughout the winding, this short-circuit would reduce the voltage between all bars to zero; but owing to the locations of the various coils with respect to the poles, their voltages differ and there will be small voltages remaining between some commutator bars; not enough, however, to support an arc. Consequently, if flashing has not started when the contactor closes, it will not start; and, if it has started, it is instantly suppressed. The second function of the flash suppressor consists in cutting down the field flux. A short-circuit through the collector rings causes a large wattless current to flow through the armature windings whose magnetizing force opposes that of the field and cuts down the voltage at the maximum safe rate, without opening either field or armature circuit.

It will thus be seen that the stored energy, not only of the line but of the machine itself, is harmlessly short-circuited through the machine and dissipated in the armature and field windings. The direct-current circuit breaker at the switchboard will be opened automatically, but only after the flash suppressor has done its work and then of course, the voltage is reduced practically to zero. The use of the flash suppressor, therefore, not only eliminates the danger to the machine from flashing, but also eliminates the necessity for opening the extremely heavy short-circuit currents with the circuit breaker, and the attendant surges in the line. In other words, the fire-works are eliminated from the substation.

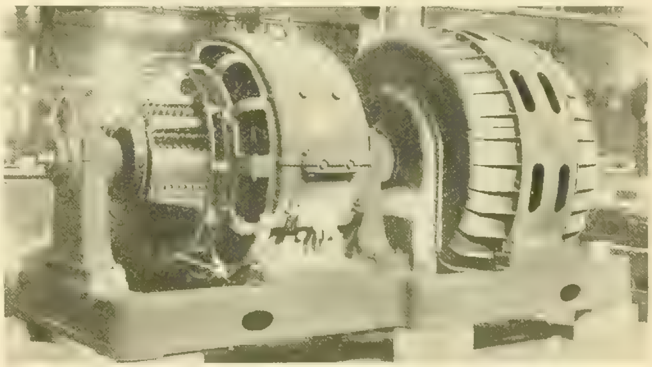


FIG. 4—1000 KW. 650 VOLT. 750 R.P.M. GENERATOR
On which short-circuit tests were made.

During the development of this method of suppressing flashing, a large number of tests were made on machines of different types and characteristics. The following tests are representative and apply to the type of generator generally used in high voltage direct-current railway service. Oscillograph records have been taken which portray the characteristics of direct-current generators on extreme overloads and the changes in these characteristics which are brought about by the application of the flash suppressor. The direct-current generator used in these tests is the 1000 kw, 650 volt, 750 r.p.m., machine shown in Fig. 4. This machine embodies no unusual design features not standard with railway generators that would tend to give it unusual momentary overload capacity.

The characteristics of this machine, on the limiting overload which it will stand without flashing, are shown in Fig. 5. During this test, the collector rings were not short-circuited, and the results are typical of a standard compensated direct-current generator. The armature current rises to a constant value of 13 000

amperes, or about eight times full load current. The total circuit resistance measured 0.0287 ohm, and the actual current obtained was 57 percent of the theoretical current that would be obtained by dividing the terminal voltage by the circuit resistance. The initial rate of current increase is about 2500 amperes per 0.001 second and the current rises to 95 percent of its final value in the first 0.010 second.

FIG. 5—ARMATURE AND FIELD CURRENTS

During maximum short-circuit possible without flashover. The breaks in the zero lines represent time intervals of 0.0167 second.

The shunt field current undergoes a sudden increase in value which is characteristic, even of compensated generators when a suddenly applied overload or a partial flash occurs. The increase of field current to 2.5 times normal value is due to flux distortions, the demagnetizing action of local currents in the commutated armature coils, and possibly to some of the commutator bars being short-circuited by the partial flashover.

With the flash suppressor adjusted for short-circuiting the alternating-current side 0.006 second after the direct-current side, Fig. 6 oscillogram was taken. This shows the direct-current, field current and collector ring voltage. Both short-circuits were made at 650 volts without resistance or reactance of any kind in the circuit. The premises outlined in the foregoing theory were completely borne out, as the flash at the commutator at the time of direct-current short-circuit was confined to a small explosive puff of extremely short duration which did not damage either brushholders or commutator surface. Many duplicate

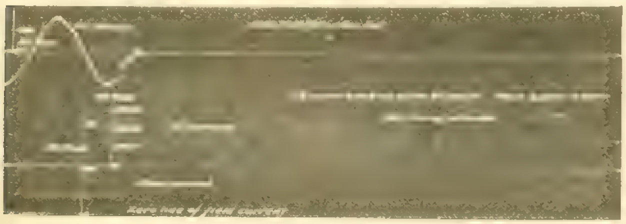


FIG. 6—OSCILLOGRAPH CURVES

With the flash suppressor adjusted to short-circuit the alternating current 0.006 second after the direct-current short-circuit occurs.

oscillograph records of combined short-circuits were made which established that the suppression of flashing is entirely independent of the point of the alternating voltage wave at which the short-circuit occurs, and that all armature positions give essentially the same effect. By this oscillogram the delay of the alternating-short-circuit behind the direct-current short-circuit may be very accurately measured.

Since the use of the flash suppressor involves short-circuiting the alternating-current side of a generator a few thousandths of a second after a direct-current overload is applied, it is of interest to know the magnitude of the alternating current flowing when the collector rings are short-circuited upon themselves. The current flowing when the alternating-current side of the machine is short-circuited is very materially less than the current flowing when the direct-current side is short-circuited, since the winding resistance is the principal limiting factor at time of direct-current short-circuit, while the winding reactance imposes greater limitation on the alternating-current short-circuit. Moreover, the polyphase reactance of the armature winding is nearly twice as great as the reactance of an alternator of equal rating, because of the large number of turns required for a given voltage in order to avoid an excessive average voltage between commutator bars.

The alternating currents in the three phases on short-circuit at full voltage are shown in Fig. 7. An analysis of the currents in all three phases indicates that the resultant current rises uniformly in magnitude until it reaches its maximum value in approx. 0.014 second (one-half cycle) after the instant of ap-

FIG. 7—ALTERNATING-CURRENT WAVES IN EACH OF THE THREE PHASES

plication of the alternating-current short-circuit. It is an inherent condition of any polyphase short-circuit that the resultant armature currents attain their maximum magnitude after one alternation from the instant of short-circuit. The armature current and field have very unusual characteristics under combined alternating and direct-current short-circuit conditions. Inspection of Fig. 6 shows that the direct-current begins to increase at the uniform rate of about 2700 amperes per 0.001 second, and in 0.006 second reaches a value of 14 000 amperes. The application of the collector ring short-circuit immediately arrests any further increase of direct-current, and in the next 0.014 second (one-half cycle) the direct-current is steadily decreased until it drops to practically zero. The large decrease of the direct-current in the 0.014 second, following the application of the alternating short-circuit, i. e., the time required for the alternating-current to attain its maximum value, is due to the well-known fact that an armature winding can deliver only a definite current on short-circuit. This current is limited by the electrical constants of the armature winding and is not affected by the number of points at which a short-circuit is applied to the winding. This simply means that the transient short-circuit current output

from the collector side is subtracted directly from the direct-current output and the decrease of direct-current corresponds exactly to the building up of the alternating short-circuit current. On each successive machine alternation, the direct-current pulsates to a maximum and minimum value of steadily decreasing magnitude. The direct-current finally settles to a constant value of about 7000 amperes (4.5 times full load) in about 0.075 second.

It will be noted that, in case of a direct-current short-circuit through a relatively low resistance, as in Fig. 5, the direct current rose only to 57 percent of the theoretical value obtained by dividing the terminal voltage by the total circuit resistance. In Fig. 6, which shows the direct-current reaching an almost constant value before the flash suppressor is actuated, the current only reached 30 percent of its theoretical short-circuit value. In this connection, extensive tests have shown that high-speed compensated generators will deliver 12 to 15 times full-load current on direct short-circuit (including the current in the flashover).

FIG. 8—OSCILLOGRAPH CURVES DURING FLASHOVER

With the flash suppressor adjusted to short-circuit the alternating-current 0.011 second after the direct-current short-circuit occurs.

This short-circuit current is about 25 to 30 percent of the theoretical short-circuit current based upon the circuit resistance, including brush contact.

The characteristic curve of the various currents are not materially changed, as the time of the alternating short-circuit is further delayed after the direct-current short-circuit is applied. Fig 8 shows the alternating-current short-circuit delayed 0.011 second after the direct-current and this condition was mainly evidenced in operaion by a slight increase in the explosive puff of the arc blowing itself out, before it had time to do any damage. The direct-current in this case rose to about 19 000 amperes, or twelve times full-load, while the field current did not rise as high as when the delay of the alternating-current short-circuit was less.

These tests were made on the machine as a separately excited shunt generator, as this is the most favorable condition for operation of railway generators which are required to function on regenerative loads. In order to establish the operating characteristics of a compound-wound machine, the series field was connected in circuit. A short-circuit on a compound machine with the alternating-current short-circuit delayed 0.010 second is shown in Fig. 9. The maximum value of the direct-current is not changed by the addition of the series field, nor is its characteristic oscillation reduced. The shunt field current is affected very considerably, due to the series field magnetization discharging through the shunt field circuit in the period before the alternating-current short-circuit is applied. The operation of the machine was not materially different as regards the volume of flash from a short-circuit, under the same conditions, as a shunt generator.

The characteristics of the direct-current wave show clearly wherein the merits of the flash suppressor lie. The application of the alternating-current short-circuit not only arrests the increase of current feeding into the direct-current short-circuit, but it actually suppresses this current to practically zero for an instant. This characteristic, in conjunction with the reduction of the voltage between commutator bars, effectually snuffs out any arc that has been started by the direct-current before the alternating-current short-circuit is applied. The direct-current rises to a sufficient value to flash, but it is removed by the alternat-

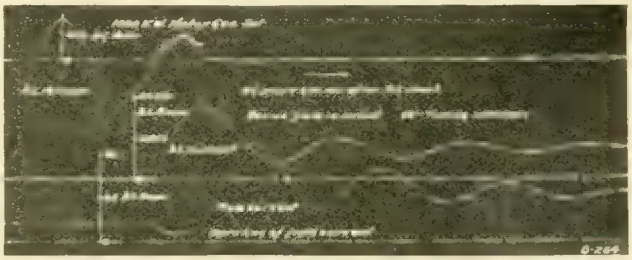


FIG. 9—OSCILLOGRAPH CURVES OF A COMPOUND-WOUND GENERATOR
With the alternating-current short-circuit delayed 0.01 second after the direct-current short-circuit.

ing-current short-circuit long before a bar can pass from one brush arm to the next, and the flash which actually gets started is summarily suppressed.

The value to which the shunt field current rises is an accurate measure of the rate at which the main field flux is reduced, and also of the voltage induced in the shunt field coils during the period of short-circuit. An inspection of the field current curve shows that the maximum current is only seven times the normal full load, so that the voltage induced in the shunt field coils is six times the excitation voltage. High-voltage railway generators are invariably separately excited at some low voltage, such as 125 volts, (of which one-half is normally consumed in field rheostat) so that an induced field voltage of six times normal is a negligible increase on field coils which are normally designed to withstand a much higher voltage.

The tests which have been described are only typical of a large number that were made during the development of the flash suppressor. All of these tests, on machines of widely different characteristics, point to the fact that in the flash suppressor has been found a real and positive preventive of flashing of direct-current railway generators.

The Engineering Evolution of Power Plant Apparatus—XXVIII

A Discussion of Recent Steam Condenser Development

R. N. Ehrhart

Condenser practice was discussed at some length in a series of articles in Vol. VI of the Journal from July to December inclusive, and in July of Vol. VII. The present article may be considered as supplementary to the above series, bringing it up to date and reviewing the latest developments. (Ed.)

The history of the condenser begins with that of the steam engine. It is difficult to trace the ancestry of the condenser back to the days of antiquity, which saw the birth of Hero's turbine, yet one might facetiously argue that condensers were known to the Greeks, since a knowledge of the subject of condensation was certainly shown in a passage which occurs in the Odyssy—"Olympus, abode of the Gods, down whose slopes condensing vapors flow." The steam motor and condenser are so closely associated that an advance in the art of one compels a corresponding advance in the other. As engines grew in size and efficiency, the condenser likewise improved, and when the steam turbine came into prominence it became evident that to realize its maximum efficiency tremendous advances had to be made in condenser practice. The steam turbine owes a great measure of its success to

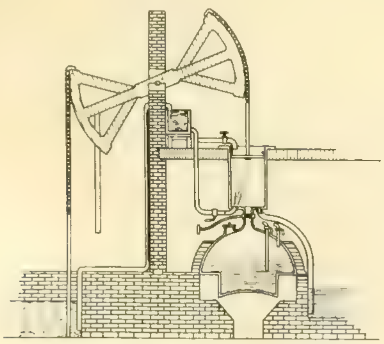


FIG. 1—NEWCOMEN ENGINE, 1705 A. D.

the development of condensing apparatus. Condenser performance that is today considered ordinary was a few years ago only a laboratory possibility.

The earliest steam engines were of the condensing type. Before the days of James Watt, the engine cylinder was both the power developer and condenser. Usually the boilers developed steam at about atmospheric pressure, as the mechanic arts had not developed to a point where high pressure boilers were possible. The working cycle was about as follows: Steam was turned into the cylinder, but as the steam pressure was approximately that of the atmosphere, the piston was not moved; then water was sprayed into the cylinder, condensing the steam and creating a partial vacuum, that is, the pressure was reduced below that of the atmosphere. The preponderating pressure of the atmosphere then moved the piston, which was generally connected to a pump plunger, as nearly all of these earlier engines were devoted to mine pumping. The cycle was then repeated after the weight of the pump plunger had returned the piston to its original position. This type of engine, known as the Newcomen engine, Fig. 1, had a great disadvantage in that the cylinder walls were chilled by having the water sprayed into the cylinder, and later heated by the incoming steam. Consequently a great amount of heat energy was lost in having to heat the chilled cylinder walls at every cycle.

James Watt's classic experiments showed a great gain in efficiency by segregating the condensing function from the engine cylinder. With the condenser separated from the cylinder, as in Fig. 2, the cylinder walls were not cooled to a low temperature and later heated by the entering steam, with a consequent absorption of useful heat energy.

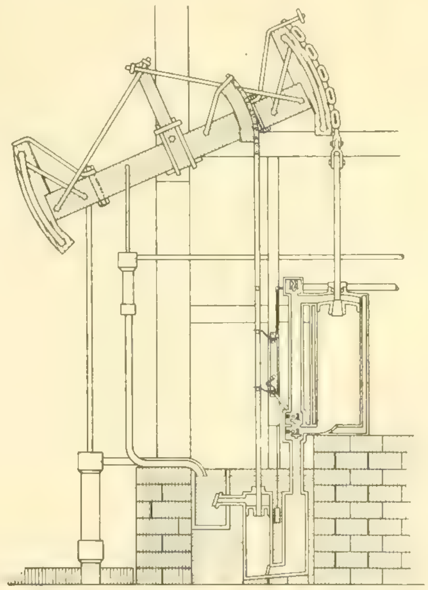


FIG. 2—WATT PUMPING ENGINE, 1769 A. D.

By the year 1800, the development of the essential elements of the Watt engine-condenser was about completed. It is scarcely believable that the lapse of nearly a century contributed substantially nothing to the development of the condenser, other than mechanical improvements, yet condensers built about the beginning of the twentieth century were not unlike those in use at the beginning of the nineteenth, as far as the essential features were concerned.

With the advent of the steam turbine, which for all practical purposes was about the year 1900, came pronounced activity in the development of the condenser. Centrifugal pumps rapidly displaced those of the reciprocating type for the handling of water. Air

pumps were separated from the other pumps. In the Watt condenser a single pump handled condensing water, condensate and air in the jet type, and condensate and air in the surface type. The separation of the air pump marked a distinct step in advance. Higher vacua were maintained with the "dry air" pump than with the old "wet pump." The advantage of having a separate air pump is manifest, inasmuch as the air handling problem is solved by the use of a pump designed only for that purpose, instead of trying to make a single pump to handle both air and water, when each requires a separate design.

About 1908 an entirely new epoch began in condenser history. While in a general way it was realized that the efficiency of the air pump had a great deal of effect on condenser performance, it was not conceded that material improvement could be made in the reciprocating air pumps then built. These pumps were indeed splendid pieces of machinery, costly, well built and skillfully designed.

The hydraulic air pump, small and compact, made its appearance. Its size and simplicity as compared with the reciprocating pump, made a contrast that was nothing less than ludicrous. It encountered a storm of ridicule on its introduction. One's credulity was taxed to the utmost to believe that the diminutive hydraulic air pump could exceed in efficiency the highly organized and developed reciprocating pump. The reciprocating pump, however, concealed certain inherent weaknesses. Although tight when new, it leaked when worn by a moderate length of service. Its tremendous ratio of compression required less clearance than was actually practicable, and the impossibility of perfect cooling of the air by jackets prevented efficient operation. In other words, here was an apparatus, well built and designed but possessing certain inherent defects that could not be overcome. Parsons was one of the first to realize some of the shortcomings of the reciprocating pump, and developed his "augmenter system," in which a steam jet is used to augment the vacuum that can be maintained by the reciprocating pump. However, this system is rather circumscribed in its application and has not achieved much prominence except in marine work.

The hydraulic air pump had none of the defects of the reciprocating pump; its very simplicity made it impossible to have the shortcomings of the complicated mechanical apparatus it displaced. The primitive form of hydraulic air exhauster had been known for very many years, but its great drawback was the great amount of power required for its operation. The earlier types consisted of nothing more than a jet of water enclosed in a proper casing; the smooth jet of water, by friction, dragged a small amount of air with it. Leblanc's invention consists of a mechanically formed jet, broken up into many laminæ, so that instead of having only the friction of a smooth jet to entrain air we have the effect of a series of pistons which entrain many times as much air for the same power consumed. The Leblanc type of pump gradually assumed the most important place in condenser work. Today it has practically driven the reciprocating pump from the field.

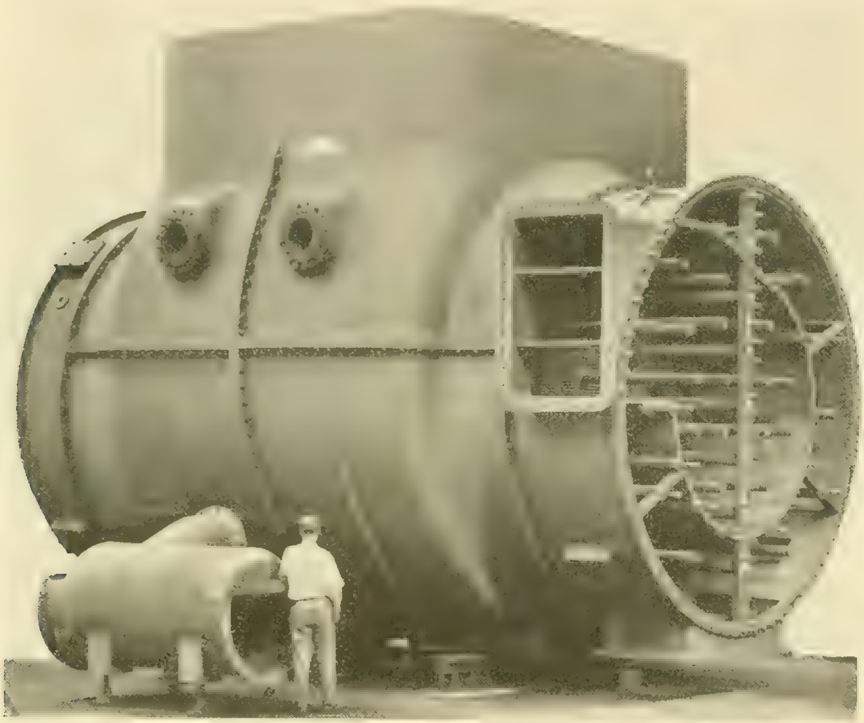


FIG. 3—1250 SQUARE FOOT AND 50 000 SQUARE FOOT SURFACE CONDENSERS
For use with 500 and 30 000 kw steam turbines.

As the size of prime movers increased, the condenser sizes increased even more rapidly. Twenty years ago, when 27 inches vacuum was considered sufficient, the condenser was but a small part of the turbine-

condenser combination. As turbine designs were improved, 28, 28.5 and 29 inches vacuum became desirable, and the condenser correspondingly increased in size, until today the condenser is physically the larger part of the combined apparatus. Figs. 3 and 4 are

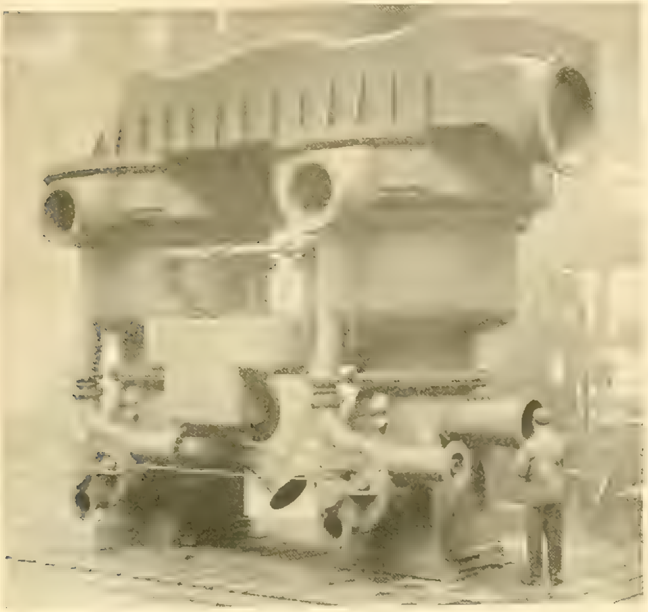


FIG. 4—TWIN TYPE JET CONDENSER
For use with a 45 000 kw steam turbine.

given to show the great size of some of our modern condensers.

With the great increase in size during the last decade, there has come an increase in efficiency. Special studies have been made towards more efficient mixture

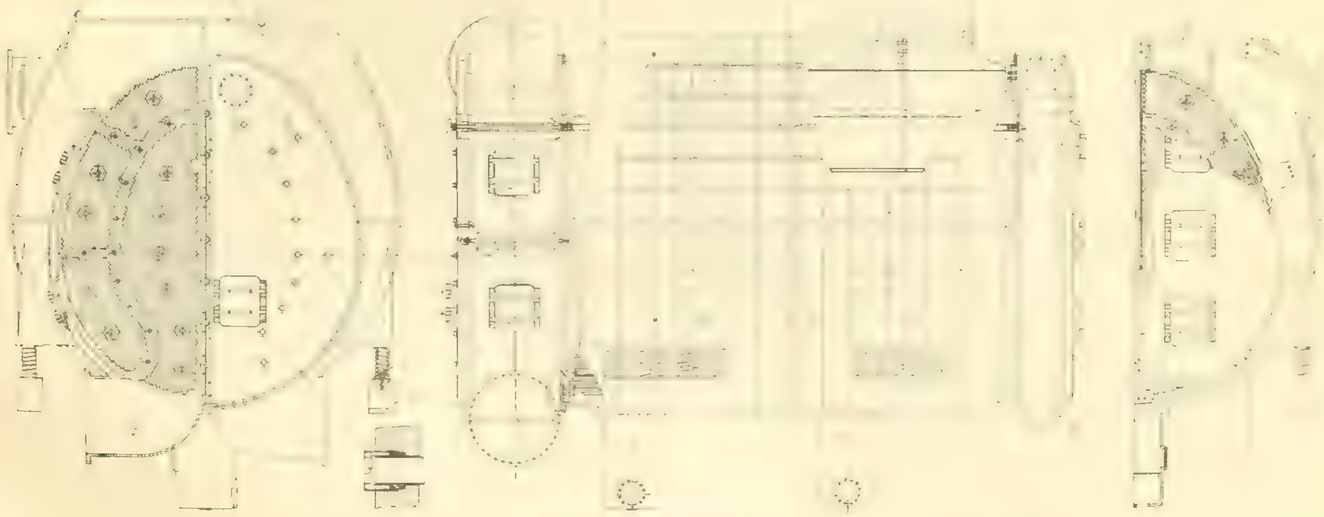


FIG. 5—50 000 SQUARE FOOT, RADIAL FLOW CONDENSER SERVING A 35 000 KW TURBINE
1—Exhaust connection; *2*—Water discharge; *3*—Water inlet; *4*—Water reversing chamber; *5*—Condensate well; *6*—Condenser support spring; *7*—Condenser spring support; *8*—Tube support; *9*—Tube plate; *10*—Manhole cover; *11* & *12*—Air outlet connections

in jet condensers, better tube arrangements in surface outfits, and the increase in efficiency of the condenser pumps and auxiliaries.

Most of the larger turbine units are equipped with surface condensers. These large condensers present a difficult problem. The length of the "flow path" is so great that the general tendency is to have a great loss in the effective vacuum produced. The vacuum might be high at the terminal point of steam flow, but due to the frictional losses it would be low in the turbine exhaust. The Westinghouse radial flow condenser was designed to overcome these difficulties, and for large condensers marks a new step in progress. In this design the tubes are so grouped that steam is admitted around the whole

FIG. 6—CIRCULATING PUMP FOR A LARGE CONDENSER

periphery, thus giving plenty of inlet area with low velocity, and a consequent reduction in frictional loss. Air is taken out of the center of the tube nest, so that the length of flow path is reduced to a minimum. This condenser has been applied to turbines of the largest size, and is giving most excellent results. A condenser of 50 000 sq. ft. capacity, which serves a 35 000 kw turbine is shown in Fig. 5.

The improvement in auxiliaries alone could be the subject of a comprehensive history. Ten years ago the small turbine began to figure prominently as a prime mover, but was available only for direct connection to pumps and other auxiliaries. It was frequently used, but was relatively inefficient, as the desirable speed of the turbine could be harmonized only in a few cases

with the desired moderate speed of the driven element. The development of the gear within the last few years has made the turbine the ideal means of driving condenser auxiliaries. By means of the gear, the driving and driven elements can each operate at their most desirable speeds. Some years ago a prime mover of 500 horse-power was regarded as a unit of some substantial capacity. It is enlightening to know that today some condensers require more than this for driving their pumps. This fact brings clearly to mind the tremendous size to which our condensing plants have grown. Today we have condensing plants serving turbines of one hundred thousand horse-power capacity. Fig. 6 shows a circulating pump for a large condenser.

The Westinghouse Electric & Mfg. Company have built some very exceptional condensing plants for marine work. These installations are of interest, inasmuch as they make use of another epoch-making invention—the steam air ejector. This is an air pump with no moving parts, extremely light in weight and more efficient than the pumps which it displaces.

In conclusion, the first great epoch in condenser work was from 1785 to 1800, James Watt laying down the principles of design, which were subject to little improvement for one hundred years. With the beginning of the present century, came an epoch in which new principles and ideas are introduced which, in connection with increasing size, make it evident that there has been a greater development in the last twenty than in the preceeding one hundred years.

An Interesting Application of a Reduction Gear

T. E. Keating

THE HOPE Natural Gas Company have a pumping station at Hastings, West Virginia, which serves as the distribution center for the gas this company supplies to West Virginia, Western Pennsylvania and parts of Ohio. When the gas wells are first tapped, pressures varying from 600 to 1000 pounds per square inch are usually obtained, but with continuous use of the gas the pressures fall to an average of about thirty pounds per square inch, in some wells gas being drawn out at near atmospheric pressure. In order to compress this gas to a proper distribution pressure for the hundreds of miles of piping employed, powerful pumping stations are required. These compressors may be driven by either steam or gas engines. In the Hastings station both types are employed, compressing the gas to a discharge pressure of 325 pounds per square inch. The necessity for additional pumping capacity at this station and an investigation into the relative efficiencies of extensions of the gas-driven and steam-driven compressors lead to the installation of the very novel equipment here described.

FIG. 1—A LOW-PRESSURE STEAM TURBINE-DRIVEN COMPRESSOR UNIT, RATED AT 3000 COMPRESSOR INDICATED HORSE POWER

This unit consists of a Westinghouse-Parsons double-flow, low-pressure steam turbine, a Westinghouse reduction gear, reciprocating parts, and two Ingersoll-Rand Gas compressors. The turbine operates at a speed of 1500 r.p.m. and is connected to the pinion of the reduction gear. On each side of the gear case are standard extra heavy engine frames, carrying the reciprocating parts driven by the cranks on each end of the slow-speed shaft of the reduction gear. To the end of each engine frame is secured a 24 by 36 inch Ingersoll-Rand hurricane valve reciprocating compressor. The turbine receives its steam from the exhaust of the cross-compound Corliss engines and in turn exhausts at a pressure of about one pound absolute, into a Westinghouse-Leblanc condenser, installed directly under the exhaust openings of the turbine.

The steam plant consists of twelve 375 horse-power, gas-fired, water-tube boilers operating under 140 lbs. pressure with no superheat. There are nine compressor units, the steam end of each consisting of a 27 by 54 by 60 inch National Transit cross-compound engine, operating at 70 r.p.m. Four of the units are direct connected to National Transit 37.5 by 60 inch Corliss, low-pressure compressing cylinders, operating with 5 pounds suction and 45 pounds discharge. The other five engines are direct connected to 20 by 60 inch Ingersoll-Rand hurricane inlet, high-pressure compressing

cylinders, operating with 45 pounds suction and 325 pounds discharge. All the engines operate condensing, the vacuum averaging from 20 to 24 inches, maintained by jet condensers with wet vacuum pumps.

Adjoining the steam plant is a gas-engine station consisting of four 38.5 by 60 inch Snow single-crank gas pumpers, two of them being direct connected to 24 by 60 inch compressing cylinders, operating with 70 lbs. suction and 325 lbs. discharge, with an average speed of 80 r.p.m.

In discussing the best method of meeting the demand for additional capacity, the suggestion was made by Mr. Cooper, engineer of the Hope Natural Gas Company, that the efficiency of the station might be improved to a greater extent by the installation of a low-pressure turbine in the steam plant, than by a gas engine unit in the gas driven station. Inasmuch as a turbine installation involved a reduction gear for connection to the reciprocating compressors, and the adaptation of a high-speed turbine and reduction gear for this purpose was somewhat revolutionary and, furthermore, as there were not sufficient data at hand to determine the relative efficiency of the steam engine—turbine combination and the gas driven units, arrangements were made to conduct tests on the steam engines under both condensing and non-condensing operation. Meanwhile Westinghouse engineers, in collaboration with the Ingersoll-Rand Company, investigated the practicability of constructing a reduction gear unit suitable for the rigid service required to drive reciprocating compressors.

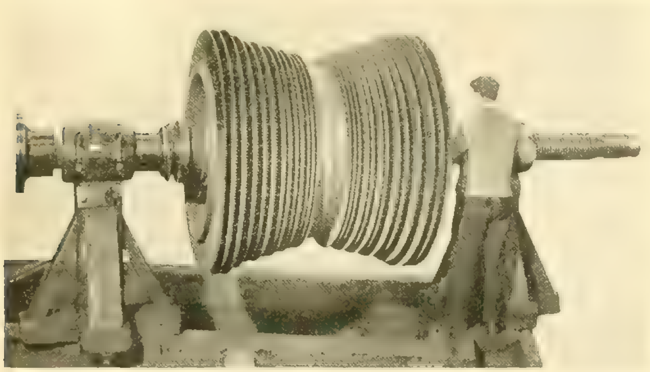


FIG. 2—THE TURBINE ROTOR

All the blades are of the reaction type. Steam is admitted at the middle of the spindle and flows in opposite directions to the exhaust chamber of the turbine casing.

The object of the steam tests conducted was to determine the amount of steam required to develop a horse-power in the compressor cylinders under existing condensing operation, as well as the steam consumption under non-condensing operation in order to estimate the gain by use of an exhaust steam turbine. Due to the operating conditions it was not feasible or necessary to conduct an economy test on the engine and compressor segregated from the condensing equipment, as the pump drive for the wet vacuum pump exhausted into the main condenser, and it was furthermore the plan to lead the exhaust of the future auxiliary drive into the low pressure turbine.

With a gas suction pressure of 94.5 lbs. and discharge of 325 lbs., peak load on the compressor cylinders, the engine developed 1660 compressor horse-power at a rate of 19.6 lbs. of steam per compressor indicated horse-power hour. On this test the steam throttle pressure was 134.4 lbs. gauge, receiver pressures 17 lbs. and vacuum 21.46 inches, referred to a 30 inch barometer. The following day a non-condensing test was conducted with 131 lbs. gauge steam pressure and 0.4 lbs. back pressure. With 52 lbs. gas suction pressure and 334 lbs. discharge, the engine developed 1650 compressor indicated horse-power, with a steam consumption of 24.5 lbs, steam per compressor indicated horse-power hour. Indicator cards were taken on both the steam cylinders and gas cylinders showing an average value of 89 percent efficiency between the steam and gas ends.

As there were nine steam engine units in the plant it was not considered advisable to figure on a low-pressure turbine for each engine, and estimates for the first unit were based on a turbine of sufficient capacity to utilize the full exhaust of two engines, but the piping arranged to accommodate the exhaust of three engines. In this way it is possible to operate the turbine in conjunction with any two of three engines at full capacity, or all three engines operating at somewhat below full rating.

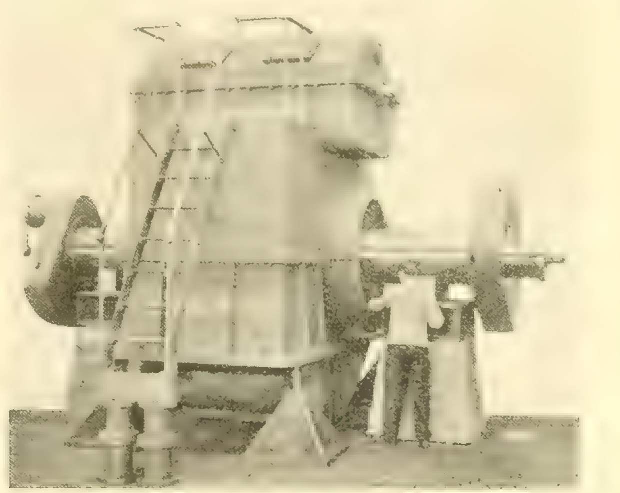


FIG. 3—COMPLETELY ASSEMBLED FLEXIBLE PINION REDUCTION GEAR, WITH THE COMPRESSOR CRANKS PRESSED ON THE ENDS OF THE SLOW-SPEED SHAFT

The pinion, in its flexible frame, operates at a speed of 1500 r.p.m. and the slow-speed shaft at 120 r.p.m. The gear teeth are of the double helical type.

Inasmuch as the determining factor from a fuel standpoint is the amount of gas required to develop a compressor horse-power it is necessary to reduce the test data to this basis. The Corliss engines are capable of developing 1660 compressor indicated horse-power when running condensing at a rate of 19.6 lbs. steam per compressor indicated horse-power hour including the steam required for the condenser serving the engine. As 1.5 cu. ft. of gas are required under the boilers to develop one pound of steam, the gas consumption rate for the engines running condensing is 29.3 cu. ft. per

compressor indicated horse-power. With two engines running non-condensing, each developing 1660 compressor indicated horse-power, there would be required 81 400 lbs. of steam per hour. Assuming this steam is exhausted into a low-pressure turbine served by a jet condenser, there would be developed in the turbine 3050 compressor indicated horse-power. This is based on using the exhaust steam of the turbine-driven pumps and deducting for the moisture content due to condensation. This gives a total of 6370 compressor indicated horse-power developed by the two engines and turbine at a rate of 21.2 cu. ft. of gas per compressor indicated horse-power-hour.

The saving by the exhaust steam turbine installation amounts to not less than 27.5 percent, that is, with two engines and the turbine operating as a unit and running at full capacity, and delivering a certain quantity of gas, the gas consumed for fuel is 27.5 percent less than would be the case were that same quantity of gas pumped by engines only, but running condensing —or to put it another way, with the same quantity of

FIG. 4—THE MAIN DRIVEN GEAR WITH ITS SHAFT AND COMPRESSOR CRANKS

The gear is of the built-up type, the teeth being cut in removable rims. The cranks are of cast steel with the crank pins an integral part of the castings. The diameter of the gear is ten feet.

gas used as fuel, the gas pumped by the engine-turbine combination would be 38 percent greater in volume than would be pumped by the engines alone, exhausting into their own condensers.

More important than the fuel consumption and first cost of the turbine geared unit was assurance that this equipment would be able to meet the severe duty required and give continuous service. The Ingersoll-Rand gas compressing cylinders contemplated were among the largest in the country for this purpose, and unusually heavy cranks and cross-head slide frames were required to transmit the 3000 horse-power for the relatively short stroke used. This in turn meant particularly severe duty on the gear. While reduction gears had been built to transmit greater horse-power, none had been contemplated for such power with the irregular force resulting from reciprocating pistons driven by cranks set at 90 degrees, and it is very doubtful if this problem could have been met successfully, if it were not for the flexible frame arrangement of the Westinghouse reduction gear which permits and maintains very uniformly distributed tooth pressures.

If a rigid frame [illegible] were installed, very slight errors of alignment in gear and pinion axes, such as are

FIG. 5—PINION AND FRAME REMOVED FROM GEAR BOX

liable to occur in this service where the gear is not subject to uniform pressure throughout a complete revolution, would lead to serious reduction in length of tooth contacts and consequently to more than proportionate rises of the maximum stresses as the intensity of pressure at the reduced contacts is necessarily very unevenly distributed. The possibility of this difficulty is entirely avoided by the introduction of the flexible frame feature, by means of which the position of the pinion shaft is wholly controlled by the interaction of the teeth in contact.

The object of the flexible frame construction is the elimination of the concentration of tooth pressures due to slight errors in alignment caused either by careless erection or conditions arising incidental to operation. It is not intended that this feature will compensate for errors in gear cutting as has been wrongly assumed by many engineers. Almost perfect accuracy in tooth cutting is just as essential in flexible frame gear applications as in rigid frames, and the adjustment of the gear cutters is continually checked to make certain of the degree of refinement required.

The principle upon which this non-rigid type of pinion support is based is shown in Fig. 5. The pinion

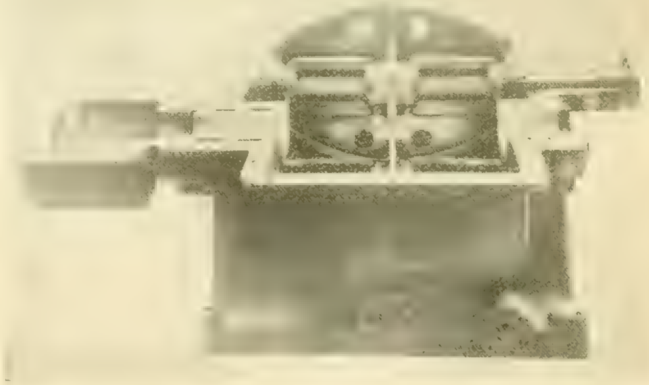


FIG. 6—PINION AND FRAME MOUNTED ON I BEAM SECTION IN GEAR BOX

bearings are carried in a very stiff frame supported at the middle of its length by an I-beam section, the flexibility being provided by the web of the I-beam. When

the teeth are not in mesh the pinion support is quite free to move about an axis transverse to the axes of the gear and pinion, and when the teeth are in mesh the exact operating position of the pinion is determined principally by the interaction of the teeth. In this manner slight errors of alignment arising from improper erection or incidental to operation, as for example temperature variations, are compensated, allowing equality of tooth pressure distribution.

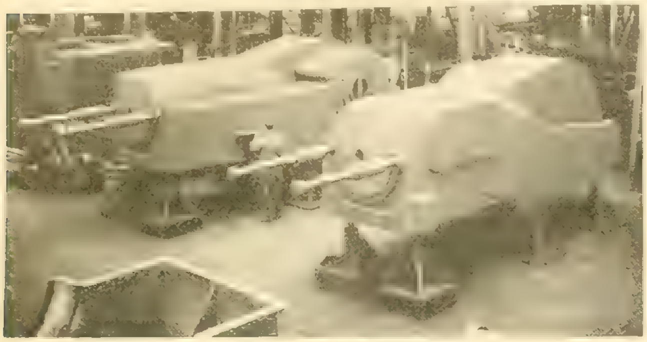


FIG. 7—COMPRESSOR SIDE FRAMES

These frames, which are installed on each side of the main gear casing, are the heaviest for the length of the stroke (36 inches) ever made in this country. Through each is transmitted 1500 horse-power. The main bearing is 22 by 38 inches, the crank pin 13 by 13 inches, and the crosshead pins 11 by 13 inches.

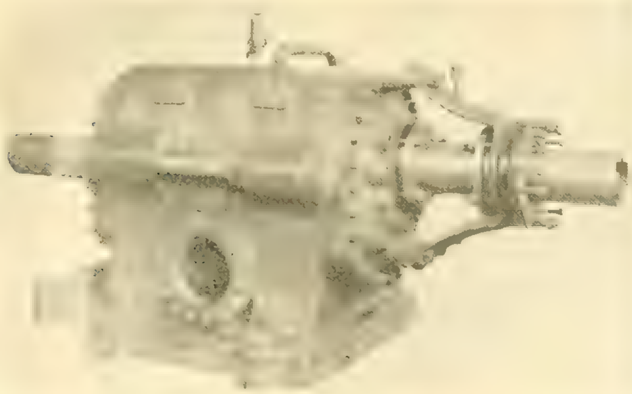


FIG. 8—COMPRESSOR CYLINDERS

The cylinders in this unit are among the largest in use in gas-compressing service. Each has a diameter of 27 inches and the piston has a stroke of 36 inches. They are designed to operate against a discharge head of 325 lbs. gage. The heads are made of steel. The inlet valves are of the "hurricane inlet" type, and the discharge valves are of the "inside guide hollow stem direct lift cushioned" type. With an intake pressure of 109.5 lbs. gage (peak load intake) the energy consumed in compressing gas is 3040 horse-power and the actual free gas delivery per 24 hours is 466 000 000 cubic feet.

It is customary to place the gear and pinion axes in a horizontal plane as indicated in Fig. 6, but in the installation under discussion the pinion was placed above the gear as shown in the illustration Fig. 3. When freedom of adjustment is permitted in the vertical plane of the pinion due to the flexure of the web, horizontal motion which would cause instability and irregular depth of tooth mesh is prevented by means of struts bearing against the pinion frame. In the case of the gear driving reciprocating compressors through cranks set at ninety degrees the angular variation in torque would set up a weaving motion in the gear shaft. In order to provide for this irregularity the pinion was set above the gear, the pinion frame being held rigid in the vertical plane and freedom of motion allowed in the horizontal plane.

FIG. 9—WESTINGHOUSE-LEBLANC CONDENSER

This condenser, through its double inlet, is directly connected to the double exhaust outlets of the turbine. The circulating or discharge water pump is directly underneath the condenser mixing chamber and the Leblanc rotating type air pump is bolted on the side of the pump chamber. The pump runner of the circulating pump and the air pump runner are mounted on the same shaft. These are the only moving parts of the condenser, there being no reciprocating parts or valves. The condenser drive connects to the flanged coupling shown in the lower left hand side of the figure.

The installation has been eminently successful and in four years of service has proven itself capable of meeting and sustaining the severe duties imposed upon it. During a period of long continued demand for gas the unit operated at approximately rated capacity for fifteen weeks without shut down. Incidentally the farsightedness of the engineers in installing steam driven compressors is demonstrated by the fact that they have since rebuilt the boiler settings for mechanical stokers finding it more profitable to burn coal and sell the gas than to use it as fuel.

Armature Reaction in Single-Phase Alternators

F. D. Newbury

THIS ARTICLE is a continuation of the one on "Armature Reaction of Polyphase Alternators" in the April issue. Figure numbers below 17 refer to the previous article.

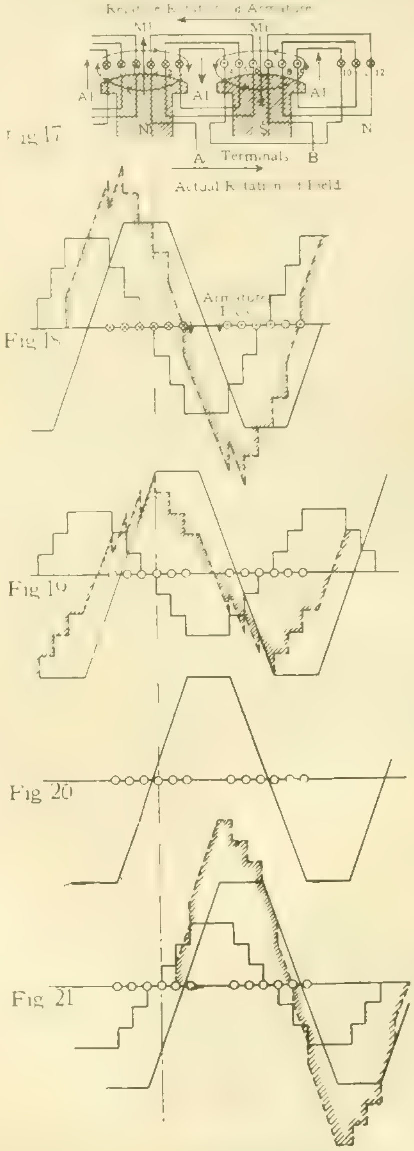
SINGLE-PHASE armature reaction may be investigated by the same methods as have been employed for the study of polyphase reaction. The single-phase winding will be assumed to have six slots per pole and the coils per pole arranged in two groups, as shown in Fig. 17. This should be compared with Fig. 3. The directions of voltages and currents and fluxes (at 100 percent power-factor) are determined by the elementary principles already covered. The field set up by the current in the armature winding with the current in phase with the no-load voltage is shown for different positions of the rotor in Figs. 18 to 21. This flux is an alternating field, stationary in space instead of the rotating field, constant in magnitude, that results from the polyphase currents. Thus, in Fig. 18, the armature flux has its maximum value; in Fig. 19 it has decreased to 0.7 of this; while in Fig. 20 the armature field has entirely disappeared.

The effect of change of current phase is to change the relative positions of the maximum armature field and the rotor. In Fig. 18, the rotor is 90 degrees ahead of the maximum armature field. In Fig. 22, showing the conditions for maximum armature current when the current lags behind the no-load voltage 90 degrees, the armature field directly opposes the main field.

The voltage generated in the armature winding at the instants of time corresponding to the rotor positions of Figs. 18 to 21 is proportional to the sum of the resultant flux ordinates immediately over the several conductors of the winding. If the generated voltage wave is obtained in this way, using first, the no-load flux curve; second, the full-load, 100 percent power-factor resultant flux curve; and, finally, the full-load zero power-factor resultant flux curve, it will be found that these three voltage curves are exactly the same in value and phase. From this it would appear that, in the single-phase alternator, neither the power-factor nor the value of the armature current has any effect tending to reduce the generated voltage. This, of course, is contrary to experience; yet the flux diagrams shown are correct. The explanation of this apparent contradiction is that the simple single-phase armature field as shown never exists in a practical generator; it can only exist when the rotor is not present or in a generator having a perfectly laminated and insulated rotor.

It will be observed from the diagrams representing this single-phase armature flux that the m.m.f. is alternating and stationary in space with respect to the armature conductors. With the type of winding shown by Fig. 17, in which adjacent groups of coils are connected in the winding in reverse directions, this alternating field generates a voltage in one group of coil sides that is equal and opposite to the voltage generated in the adjacent group of coil sides. Thus in each group of slots and, consequently, in the complete winding, the effect of the armature flux on the generated voltage is nil.

This alternating armature flux can only exist when the rotor is absent or in the ideal case of a perfectly laminated rotor, because the presence of any conducting circuit in the path of this flux brings into existence secondary currents and fluxes that modify the armature flux and tend to wipe out that part of the armature flux that varies with respect to the rotor. The alternator with a perfectly laminated rotor is like a transformer with the secondary circuit open. The entire armature flux is "leakage" flux and is effective in generating the counter e.m.f. of self-induction. Thus, with normal voltage generated in the winding, only a negligible current can be drawn from the armature, corresponding to the magnetizing current of a transformer with open secondary. The single-phase alternator, like the transformer, can only have an appreciable current flowing when the flux due to the armature (or primary) current is neutralized to a greater or lesser degree by an opposing secondary flux. In an alternator with a completely laminated rotor, this secondary circuit is absent or, at best, very ineffective, and



FIGS. 17 TO 21 SUCCESSIVE FLUX DIAGRAMS

the armature circuit has very high inductance; if, however, a cage winding of low resistance is added to the rotor, a very effective secondary circuit is provided, and practically all flux variation with respect to the rotor is eliminated. With a perfectly laminated rotor the single-phase armature reaction is that shown by the diagrams; the armature impedance is very high and the alternator cannot maintain its voltage with an appreciable load. With a perfect damping winding on the rotor, the single-phase reaction is so modified that there is no flux variation with respect to the rotor, and, consequently, the single-phase reaction is actually very different from the fields shown in the diagrams and, in effect, is the same as a polyphase reaction.

This transformation of the single-phase magnetic field into a field having the same characteristics as the field set up by a polyphase winding is most readily explained by means of diagrams of the fluxes existing at different instants of time. In the single-phase generator with a cage winding on the rotor, there exists the flux due to current in the single-phase armature winding; a flux due to polyphase currents induced in the cage winding by the single-phase armature flux; and, finally, a resultant of these two fluxes which is the true armature reaction.

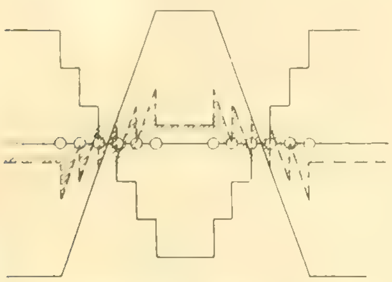
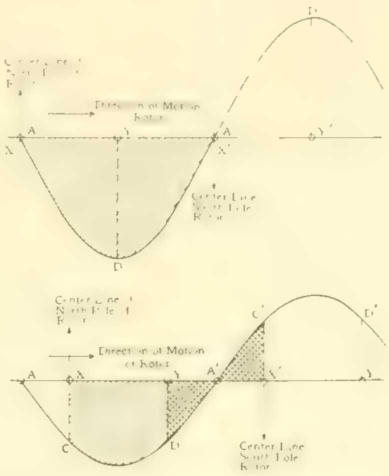


FIG. 22 EFFECT OF LAGGING CURRENT

To simplify the diagrams, it will be assumed that the armature flux has a sine shape, instead of the stepped form, as previously used, and that the armature winding is concentrated in two slots. In Fig. 23 this armature coil is represented at AA' and the shape of the armature flux in space is represented by the sine curve ADA'. The position of the armature flux is determined by the space position of the armature coil. The simultaneous position of the rotor poles and the direction of motion are as shown, and correspond to the assumptions made in the previous diagrams. The cage winding is represented by two coils spaced 90 degrees apart, XX' (located on the centers of adjacent poles) and YY' (located midway between poles). The cage winding is, in effect, a polyphase winding having as many phases as there are bars per pole, but its effects can be shown equally well by treating it as a two-phase winding. Consider first the voltages generated in the cage winding by the alternating armature flux as if the two-cage winding phase circuits were open. This voltage is due to two actions, the transformer action of the alternating armature flux and the generator action of the rotating winding. There would be a voltage generated in the cage winding, due to the varying armature field, even though the cage winding did not rotate, and similarly, there would be a voltage generated in the cage winding due to its rotation, even though the armature field were constant. The combined effect of these actions can be observed by determining the total flux enclosed by the two coils representing the cage winding at different times. The voltage generated in the coils will be proportional to the change in flux enclosed during equal intervals of time. Thus, in Fig. 23, the coil XX' of the cage winding is exactly opposite the armature coil and encloses the total armature flux of one polarity. In Fig. 24 the relations existing after the rotor has moved 45 degrees are illustrated. The armature flux has the same position as in Fig. 23, but has decreased to 0.7 of its former value. The movement of the rotor has carried the cage winding coil XX' to a new position, such that it encloses three-quarters of the armature flux of one polarity and one-quarter of the flux of the opposite polarity. The effective armature flux enclosed by the cage winding coil XX' is that part $XCDY$ (shown with single cross-hatching). The effect of the armature flux $YA'D$ is neutralizied by that of the flux AXC. Thus by rotating the cage winding coil 45 degrees, the effective flux enclosed by it has decreased from the value represented by the area XDX', in Fig. 23, to the value represented by the area $XCDY$, in Fig. 24. If the area of XDX' is taken as unity, the area of $XCDY$ will be 0.50; the difference between these areas (0.50) is proportional to the change in flux and, consequently, is proportional to the average voltage generated during this interval.



FIGS. 23 AND 24—EFFECT OF CAGE WINDING IN PRODUCING A FLUX WAVE

In Fig. 23 the cage winding coil YY' encloses one-half of the armature flux of one polarity and one-half of the flux of the other polarity; the net result is that coil YY' encloses zero flux. In Fig. 24 the coil YY' encloses net flux equal to $X'C'D'Y'$ which has the same value as the net flux enclosed by coil XX' but has the opposite polarity. Thus, the flux enclosed by coil YY' changed from zero to 0.50 in rotating 45 degrees. The direction of the voltage generated, according to the fundamental law of induction, is such as to oppose the change in flux; thus an increasing positive flux generates a negative voltage, a decreasing positive flux generates a positive voltage, a decreasing negative flux generates a negative voltage, and an increasing negative flux generates a positive voltage. Thus in coil XX' the voltage generated is negative; and in coil YY' the voltage generated is also negative.

The voltages induced in the cage winding can be determined in a similar manner for as many positions

of the rotor as desired. In Table I are shown the flux values and the change in flux for nine positions of the rotor, 22.5 degrees apart, starting with the position shown in Fig. 23. The values of enclosed flux in Table I were determined from a diagram of the form shown in Fig. 25. This shows in a convenient way the values of armature flux for the nine different times selected and shows the corresponding positions of the two cage winding coils.

Figs. 26 and 27 are plots of the flux and voltage values in the preceding table; Fig. 26 shows conditions for coil XX' and Fig. 27 for coil YY'. It will be seen at once that while the rotor has turned through 180 degrees the voltage induced in the cage winding has completed a cycle, or 360 degrees; that is, the voltage generated in the cage winding has a frequency double that of the voltage generated in the armature winding. The physical reason for this double frequency is the existence of two actions, each resulting in voltage generation: voltage is generated by the variation of the armature winding flux, as in a transformer, and voltage is generated by the rotation of the cage winding as in a revolving-armature alternator. The effects of these two

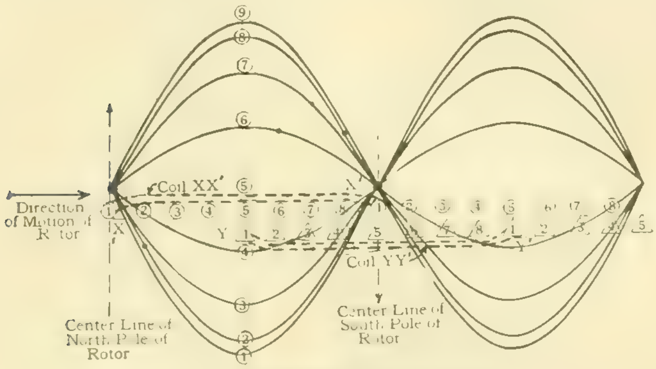


FIG. 25—ARMATURE FLUX WAVES

Taken at nine different times and positions and showing the corresponding positions of the two cage windings.

actions can be separately shown by the same methods of analysis as already used in determining the results of their combined action. First, consider winding YY', as this happens to be somewhat the simpler. If the armature flux is assumed to be constant, the flux enclosed by the coil YY' will vary, due to its rotation. This variation is readily determined from Fig. 25, using the armature flux corresponding to position (1) for all positions of the rotor. These values of flux and voltage are shown in columns *3* and *4* of Table II and in curves *1* and *A* of Fig. 28. It will be seen that the flux enclosed by the coil in various positions of the rotor varies from zero in position (1) to a maximum in position (5) and this curve has the same shape and values as the curve representing the space distribution of the armature flux in Fig. 25. The voltage, proportional to the rate of change of flux, is a sine curve of fundamental frequency lagging behind its flux by 90 degrees.

The effect of the variation in armature winding flux that actually occurs, may be seen by determining the reduction in the flux enclosed by coil YY' in each rotor position, due to the difference between the assumed constant armature winding flux and the flux that actually exists. Thus in position (1) the assumed and actual fluxes are identical. In position (2) the actual enclosed flux, considering the combined effect of motion and of the changing flux is equal to the enclosed flux based on constant armature flux, multiplied by the area enclosed by curve *2*, Fig. 25 (the area of curve 1 being unity); or it is 0.38 (column *3*, Table II) multiplied by 0.92, which equals 0.35. Column 5, Table II, shows these values for the nine rotor positions and column 6, which shows the difference between the successive flux values of column 5, with the algebraic sign reversed, represents the voltage induced by the resultant rate of change of flux. These values are identical with the values of column *6*, Table I, as they represent the same voltage.

The two sets of flux values and of voltage values are plotted in Fig. 28. Flux curve *1* and voltage curve *A* represent conditions due to rotation only—the armature flux being assumed constant at its maximum value. Flux curve *2* and voltage curve *B* represent the resultant enclosed flux and voltage induced by the combined effect of motion and change in flux. Curves *1* and *A*, based on the assumption of an exciting field of constant value, (as if, for instance, the armature winding were excited by direct-current, and the conductors were so distributed that a sine-shaped field was produced) are sine curves of fundamental frequency. The flux curve *1*, in fact, duplicates in shape the assumed constant value armature flux. The actual flux and voltage values differ from these on account of the actual reduction in armature flux values from the assumed constant values. At position *1* (zero degrees) the actual and assumed flux values are the same; at position *2*, (22.5 degrees from *1*) the actual flux enclosed is 92 percent of the assumed flux because the actual armature exciting flux has decreased to 92 percent of its assumed constant value; at position *3* (45 degrees from *1*) the actual flux enclosed by the cage winding coil is 71 percent of its assumed value; at position *4*, it is 38 percent, and at

TABLE I

(1) Position	(2) Degrees	Area of Enclosed Flux (3) By Coil XX'	Area of Enclosed Flux (4) By Coil YY'	Voltage Generated (5) In Coil XX'	Voltage Generated (6) In Coil YY'
1 (Fig. 23)	0.	1.00	00		
				0.15	−0.35
2	22.5	—0.85	+0.35		
				0.35	—0.15
3 (Fig. 24)	45	−0.50	+0.50		
				−0.35	+0.15
4	67.5	0.15	+0.35		
				—0.15	+0.35
5	90	00	00		
				+0.15	+0.35
6	112.5	—0.15	—0.35		
				+0.35	+0.15
7	135	—0.50	—0.50		
				+0.35	—0.15
8	157.5	—0.85	—0.35		
				+0.15	0.35
9	180	—1.00	00		

position 5 it has been reduced to zero because at this position the actual armature current and flux are zero. Thus, there is one zero value of enclosed flux at position *1* due to the position of the cage winding coil,—that is due to rotation, and a second zero value at position 5 due to the variation in armature flux. Beyond position 5, the direction of the enclosed flux reverses because the armature flux reverses. There is, then, a double frequency flux and voltage produced in the cage winding coil, because of the combined effect of rotation and exciting flux variation. The actions taking place in the other cage winding phase, coil XX', can be shown in the same way. The numerical values of fluxes are given in Table III, and these values are plotted in Fig. 29. While the shape of the component curves differs radically from the corresponding curves of Fig. 28, the resultant curves are the same except for the 45 degree difference in phase.

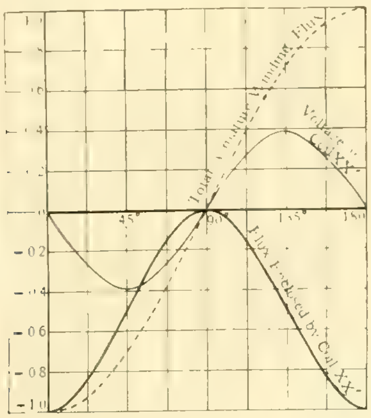


Fig. 26

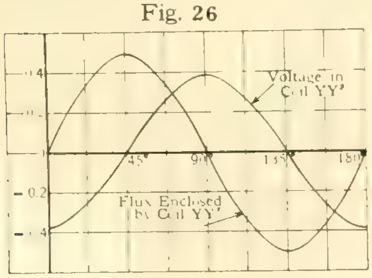


Fig. 27

FIGS. 26 AND 27—FLUX AND VOLTAGE WAVES FOR COILS XX' AND YY'

In the case of coil XX', it is possible to arrive at the same result by starting with the assumption of a stationary cage winding, determining the voltage induced by the varying armature flux and then determining the change in flux caused by rotation. The results of this method are shown in Table IV.

If the direction of the voltage generated in the armature winding by the main exciting field be determined in accordance with the same method and conventions as used for determining the direction of the voltages in the cage winding—it is found that the main voltage is negative, and has its maximum value in position *1*, Fig. 25. Fig. 30 shows the relative directions and time phases of the armature voltage and the cage-winding voltages (transferred from Figs. 28 and 29). The cage-winding currents in Fig. 30 are shown lagging one-quarter cycle behind their respective voltages. The cage-winding voltages were determined on the basis of armature current in phase with the armature voltage, and the armature current is so indicated in Fig. 30. The cage-winding currents lag one-quarter cycle, because the cage-winding circuits are practically inductive; the cage winding is effective in proportion to the approach to this condition, and in practice the resistance is made as small as practicable.

The time and space relations of the fluxes set up by the armature and cage windings are illustrated in Figs. 31 to 35. In these figures AA' is the armature coil and XX' and YY' are the cage-winding phases, as in previous diagrams. The armature and cage-winding currents produce fluxes having the same relative instantaneous values and directions as their respective currents. The space relations are determined by the positions of the several coils. Each of the diagrams show the space distribution of the fluxes at one instant of time. In Fig. 31, the time is that corresponding to zero degrees of Fig. 30, or position *1* of Fig. 25. The armature flux has its maximum negative value corresponding to the value of the current in Fig. 30. This direction is opposite to that of the trailing N pole, as previously established (Fig. 17). Coil XX' produces its maximum flux in the positive direction as shown by the current in Fig. 30, and coil YY' produces no flux, since at this instant the current in YY' is zero. The maximum value of the cage winding flux is shown as one-half the maximum value of the armature flux. This relation exists because the flux enclosed by each phase of the cage winding, as illustrated by Figs. 26 and 27, or 28 and 29, is one-half of the armature flux. The flux produced by the current in each cage-winding phase is, neglecting

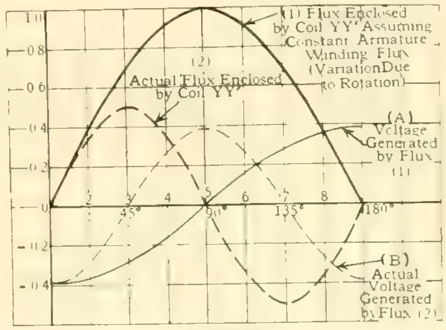


Fig. 28

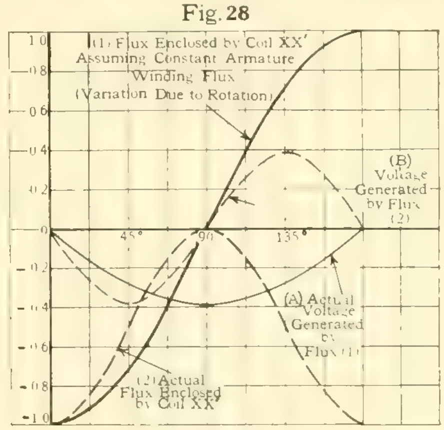


Fig. 29

FIGS. 28 AND 29—FLUX AND VOLTAGE WAVES
Assuming constant armature flux.

TABLE II—FLUXES ENCLOSED BY AND VOLTAGES INDUCED IN COIL *YY'*

Starting with assumption of constant armature flux.

(1) Position	(2) Degrees	(3)—Flux Enclosed by Coil Assuming Constant Armature Flux	(4)—Voltage Induced by Changes in (3)	(5)—Enclosed Flux Considering Combined Effect of Motion and Change of Flux	(6)—Voltage Induced by Changes in (5)
1	0	0		0 × 1.00 = 0	
			—0.38		—0.35
2	22.5	+0.38		+0.38 × (+0.92) = +0.35	
			—0.33		—0.15
3	45	+0.71		+0.71 × (+0.71) = +0.50	
			—0.21		+0.15
4	67.5	+0.92		+0.92 × (+0.38) = +0.35	
			—0.08		+0.35
5	90	+1.00		+1.00 × 0 = 0	
			+0.08		+0.35
6	112.5	+0.92		+0.92 × (—0.38) = —0.35	
			+0.21		+0.15
7	135	+0.71		+0.71 × (—0.71) = —0.50	
			+0.33		—0.15
8	157.5	+0.38		+0.38 × (—0.92) = —0.35	
			+0.38		—0.35
9	180	0		0 × 1.00 = 0	
		Curve 1, Fig. 28	Curve A, Fig. 28	Curve 2, Fig. 28	Curve B, Fig. 28

TABLE III—FLUXES ENCLOSED BY AND VOLTAGES INDUCED IN COIL *XX'*

Starting with assumption of constant armature flux.

(1) Position	(2) Degrees	(3)—Flux Enclosed by Coil Assuming Constant Armature Flux	(4)—Voltage Induced by Changes in (3)	(5)—Enclosed Flux Considering Combined Effect of Motion and Change of Flux	(6)—Voltage Induced by Changes in (5)
1	0	—1.00		—1.00 × (+1.00) = —1.00	
			—0.08		—0.15
2	22.5	—0.92		—0.92 × (+0.92) = —0.85	
			—0.21		—0.35
3	45	—0.71		—0.71 × (+0.71) = —0.50	
			—0.33		—0.35
4	67.5	—0.38		—0.38 × (+0.38) = —0.15	
			—0.38		—0.15
5	90	0		0 × 0 = 0	
			—0.38		+0.15
6	112.5	+0.38		+0.38 × (—0.38) = —0.15	
			—0.33		+0.35
7	135	+0.71		+0.71 × (—0.71) = —0.50	
			—0.21		+0.35
8	157.5	+0.92		+0.92 × (—0.92) = —0.85	
			—0.08		+0.15
9	180	+1.00		+1.00 × (—1.00) = —1.00	
		Curve 1, Fig. 29	Curve A, Fig. 29	Curve 2, Fig. 29	Curve B, Fig. 29

TABLE IV—FLUXES ENCLOSED BY AND VOLTAGES INDUCED IN COIL *XX'*

Starting with assumption of stationary cage winding coil.

(1) Position	(2) Degrees	(3)—Net Area of Armature Flux Assuming Coil Stationary	(4)—Voltage Induced by Changes in (3)	(5)—Enclosed Flux Considering Combined Effect of Motion and Change of Flux	(6)—Voltage Induced by Changes in (5)
1	0	—1.00		—1.00 × (+1.00) = —1.00	
			—0.08		—0.15
2	22.5	—0.92		—0.92 × (+0.92) = —0.85	
			—0.21		—0.35
3	45	—0.71		—0.71 × (+0.71) = —0.50	
			—0.33		—0.35
4	67.5	—0.38		—0.38 × (+0.38) = —0.15	
			—0.38		—0.15
5	90	0		0 × 0 = 0	
			—0.38		+0.15
6	112.5	+0.38		+0.38 × (—0.38) = —0.15	
			—0.33		+0.35
7	135	+0.71		+0.71 × (—0.71) = —0.50	
			—0.21		+0.35
8	157.5	+0.92		+0.92 × (—0.92) = —0.85	
			—0.08		+0.15
9	180	+1.00		+1.00 × (—1.00) = —1.00	

leakage and resistance, equal and opposite to that part of the armature flux enclosed by the cage winding. As a matter of fact, this fundamental relation gives at once the phase as well as the magnitude of the flux produced by each cage-winding phase without taking the intermediate steps of determining the cage-winding voltage and current. It will be seen that the cage-winding current curves in Fig. 30 are the images of the enclosed flux curves of Figs. 26 and 27.

The field set up by the complete cage winding at this instant is that set up by phase *XX'*. This flux combines with that of the armature winding to produce the resultant armature reaction, as shown.

At a later time, when the rotor has turned 22.5 degrees, the flux relations are as shown by Fig. 32. The armature flux occupies the same position in space, but has decreased to 92 percent of its former value (see Fig. 30). The space position of the flux due to *XX'* has advanced 22.5 degrees (with the rotor) and has decreased in magnitude to 0.7 of its former value (see Fig. 30). The current in cage-winding phase *YY'* has increased from zero to 0.7 of its maximum value, but in the opposite direction to that of the current in

XX'. The flux set up by this current is located in space by the position of coil YY' as shown. The fluxes due to the two cage-winding phases combine to form the cage-winding flux, and this, in turn, combines with the armature flux to produce the resultant armature reaction. The ordinates of the curve marked cage-winding flux are the algebraic sum of the corresponding ordinates of the curves XX' and YY'; similarly, the ordinates of the curve representing the resultant armature reaction are the algebraic sum of the corresponding values of the cage-winding flux and the armature winding flux.

Figs. 33, 34 and 35 show the armature flux, the cage-winding flux, and the resultant armature reaction for additional instants of time and positions of the rotor varying by 22.5 degrees. In each case, the values of the fluxes have been determined from the values of currents shown by Fig. 30, and the space locations have been determined by the space positions of the several windings.

Comparing the resultant fluxes shown in these figures, it is seen that the field established by the polyphase cage winding is a rotating field of constant value as in other polyphase windings; but that the speed of

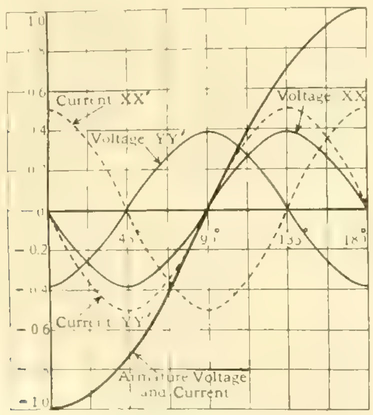
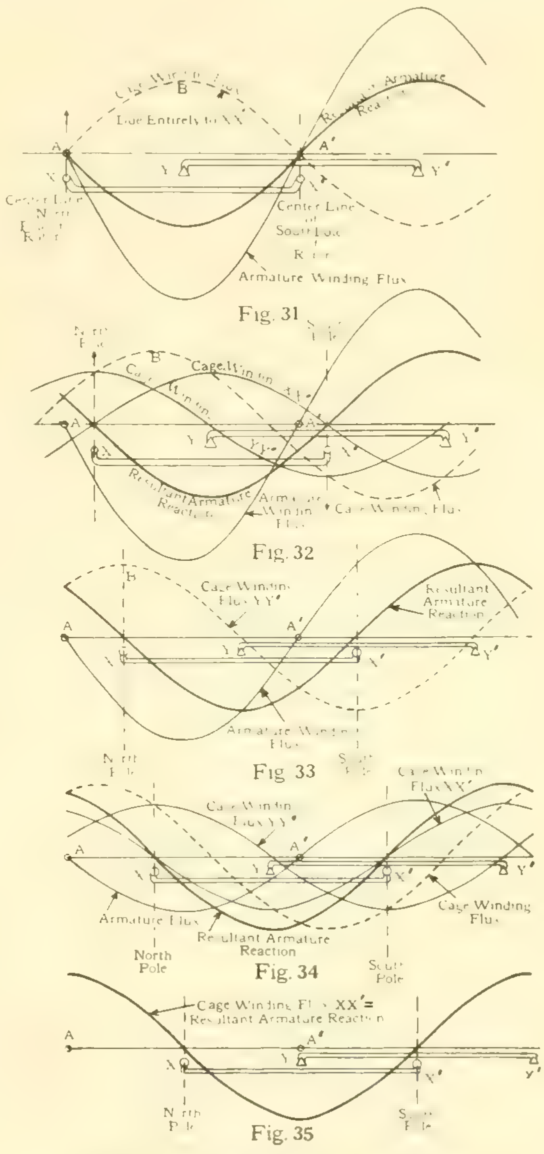


FIG. 30—RELATIVE DIRECTIONS AND TIME PHASES
Of the armature and cage-winding voltages.

rotation, with respect to the rotor, is twice the rotor speed, and the direction of rotation is contrary to that of the rotor. In Fig. 31, the maximum point of the cage-winding flux B is located midway between N and S main poles. In Fig. 33, the corresponding maximum point B is located directly in line with the N pole. Thus, while the rotor has turned 45 degrees, mechanically, the cage-winding flux has rotated one-half pole pitch or 90 degrees, with respect to the rotor. With respect to the stationary armature winding, the cage winding field has moved 45 degrees—or at the same speed as the rotor. The speed is double that of the rotor, because of the double frequency voltages and currents generated in the cage-winding by the armature flux. The opposite direction of rotation of the rotating field follows directly from the location of the cage-windings on the rotor. The reason for this may be clearer if the analogous conditions in the polyphase alternator are reviewed. With a rotating *armature* winding, the field established by the armature currents rotates in a direction contrary to that of the mechanical rotation of the winding, and is, therefore, stationary with respect to the stationary poles and exciting winding. With a rotating *field* alternator the currents generated in the stationary armature produce a field that rotates in the same direction as the rotor but still in a direction contrary to the relative motion of the armature. (See Figs. 3 and 11). The cage-winding is analogous to the armature winding in the polyphase alternator, and since the cage-winding is located on the rotor and the exciting winding is stationary, the field established by the currents in the cage-winding rotates in a direction contrary to that of the cage-winding itself, as in the rotating armature alterna-



FIGS. 31 TO 35 SUCCESSIVE FLUX WAVES

tor. Since the speed of rotation of the cage-winding field is double that of the rotor, the field rotates at synchronous speed with respect to the stationary armature winding.

It is also evident from inspection of Figs. 31 to 35 that the resultant of the armature flux and cage-winding flux—the true armature reaction—is a field of constant magnitude that is stationary in space with respect to the rotor. In each of the several figures representing different rotor positions, the curve of resultant armature reaction has its maximum value midway between

the N and S main poles of the rotor, this space position of maximum flux moving synchronously with the rotor. The resultant single-phase reaction is therefore a magnetic field of the same nature as the field set up by a polyphase winding. Thus it is that single-phase armature reaction is a special case of polyphase armature reaction.

While it has taken considerable time and space to show that the alternating field set up by the single-phase armature current does become a rotating field of constant value, the reason why can be quickly stated. As long as there is any part of the stationary alternating field due to the armature winding in existence that varies either in value or position with respect to the rotor, it generates a voltage in the rotor, and this voltage, in turn, produces a flux tending to wipe out the exciting flux. Thus with the assumptions of perfect flux linkage between the armature and cage windings, and of no loss in the cage-winding, there can be no part of the armature flux remaining, except that part that does not vary with respect to the rotor. The rotor, provided with a perfect cage-winding, obliterates all except that flux rotating synchronously with it.

In this article, the single-phase reaction has been treated as the resultant of two component fields; one component is the pulsating field due to the current in the armature winding that would exist were the rotor absent; the other component is the field set up by the current in the cage-winding, these currents being caused by the first component field. This method of analysis introduces no conceptions other than the fundamental ones of a pulsating single-phase field set up by the single-phase current in the armature winding, and the voltage generated in a second winding by the flux due to the first. From this point of view, it is correct to say that the armature reaction of a single-phase generator is a synchronously rotating field. It is not necessary to account for the double frequency current in the cage-winding by decomposing the pulsating single-phase field into two oppositely rotating fields; it follows directly from the double frequency voltage generated in the cage-winding by the combined effect of flux pulsation and winding rotation.

This conception of two oppositely rotating fields is quite generally used in explaining the actions of single-phase fields. It is easy to see that two such rotating fields are equivalent to a single pulsating field stationary in space. When the two rotating fields are in phase, the pulsating field has its maximum value. Therefore the rotating fields must have one-half the maximum value of the pulsating field. When each rotating field has turned 90 degrees they are equal and opposite; and the pulsating field is zero. At intermediate points the resultant field is constant in position and varies sinusoidally in value. By this conception the existance of double frequency currents in the cage-winding is also simply explained. The backwardly rotating component field cuts the rotor winding at double synchronous speed, and generates in it double frequency voltage; since the winding is closed, currents flow that tend to establish a field opposing the initiating field, and the voltage and current in the cage-winding increase until—barring electrical losses and flux leakage—the backwardly rotating field is completely wiped out. This component having been disposed of, there remains only the forwardly rotating field as the equivalent armature reaction.

Of course, these two methods are both correct and lead to identical results. The first method is obviously more involved and more difficult to follow. It has been used here in spite of these draw-backs because it appears to the writer as the logical step-by-step method of approach; it shows, for example, the fundamental importance of the cage-winding, that without a path for polyphase currents in the rotor the single-phase reaction would be a pulsating field and the armature could not deliver current. The two rotating field method explains what happens, while the other method, in addition, more completely explains how it happens. The expedient of two oppositely rotating fields is a short cut that is extremely useful in arriving quickly at results; the longer and more direct method is mainly of educational value.

It has been shown that the true armature reaction of the single-phase alternator is of the same nature as the armature reaction of the polyphase alternator. It follows then that the effects of armature reaction on generated voltage are also of the same nature as in the polyphase alternator. The single-phase armature reaction combines with the main flux, producing a resultant flux as shown in the diagrams of conditions in the polyphase machine. The effect of power-factor is also the same. While the analysis of single-phase reaction was based on an assumption of 100 percent power-factor, the choice of another power-factor will only have the effect of producing corresponding phase changes in the cage-winding currents and fluxes. The resultant of the armature flux and the cage-winding flux will be the same except for the different relative positions of resultant armature reaction and main exciting flux.

Correction—There is an error in the previous installment of this article that should be corrected. Fig. 5 is incorrect in that the flux of only one polarity has been considered. There is also an equal flux, opposite in polarity and displaced 180 electrical degrees from the flux shown in Fig. 5. When both these polarities are taken into account the armature flux of the winding represented by Fig. 5 is identical with that of Figs. 3 and 4. Fig. 5 and the paragraph in the middle of the second column of p. 107 referring to Fig. 5 should be omitted.

The Essentials of Transformer Practice—X

General Problems of Design

E. G. Reed

IN THE USUAL discussion of transformer design, the mathematical difficulties often obscure the actual relations between the various quantities involved. The following analysis is intended to show these relations in a general way without the use of mathematics. It is obvious that the relations between all of these variables mathematically developed would result in rather complicated operations and expressions.

TYPES OF CONSTRUCTION

The shell and core types are the two fundamental forms of transformer construction. All others are modifications of these. In the former, the iron encloses the winding like a shell, and in the latter the iron forms the core upon which the windings are mounted. The relation between these fundamental types is given in Fig. 1, which shows that an interchange of the iron and copper elements will transform the shell type into the core type, and vice versa.

A section through the copper element at right angles to the conductors is usually rectangular in shape for both the shell and core types, which also gives a rectangular section through the iron element. Sometimes the section of the iron circuit is given a cruciform shape in which case the windings take a circular form as shown in Fig. 2. This cruciform design is used mainly for the high voltage core type transformers, because of the ease with which the circular coils may be wound and because sharp bends in the insulation are avoided.

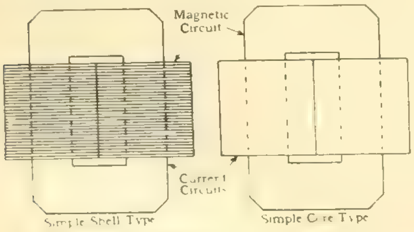


FIG. 1—FUNDAMENTAL RELATION BETWEEN SHELL AND CORE TYPE OF TRANSFORMER CONSTRUCTION

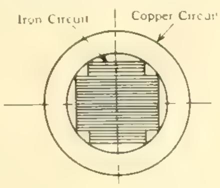


FIG. 2—SECTION THROUGH ONE SIDE OF A CORE TYPE TRANSFORMER

The development of the distributed shell and core types of construction from the simple forms, is by the addition of two smaller iron circuits to the shell type, or two small copper circuits to the core type; as shown in Fig. 3. The reason for the use of this form is the economy secured by the use of the smaller mean turn of the element which is separated or distributed into a number of parts.

In the shell type of design in all its forms and in the simple core type, it is possible to widen those portions of the magnetic circuit which are not surrounded by the windings, as shown in Figs. 1 and 2. An increase in the area of these portions of the magnetic circuit permits them to run at a lower magnetic density than the unwidened parts, thus giving a lower iron loss. When low losses are desired better results can usually be obtained by this expedient than by putting the increased material into a uniformly increased section of either iron or copper.

Another modification of the core construction is shown in Fig. 4, which is the form used for three-phase transformers. There are three separate magnetic circuits, one for each of the three-phase fluxes. Such a construction produces complications in the assembly of the various parts, which are overcome as shown in Fig. 5. While a three-phase transformer can be built with three separate magnetic circuits, the only saving as compared with three single-phase transformers, is the use of a single case as against the use of three with the single-phase units. With the three magnetic circuits interlinked, there is a saving in material in comparison with three single-phase transformers aggregating the same capacity.

SELECTION OF TRANSFORMER TYPE

The shell and core types of transformer construction each have a fairly well marked portion of the total range of k. v. a., voltage and frequency, to which it is best adapted, other conditions being the same. The most direct way to make a comparison of the relative economy of the two types for a particular transformer rating is to make comparative designs for both types, the comparison being usually made on the basis of a minimum cost of material required for a transformer which will meet given insulation tests and to have certain performance characteristics. Upon analysis it is found, on the basis of economy of material alone, that small, high-voltage transformers should be core type and large, low-voltage transformers should be shell type. Further it is found that the main factor which controls the design, as to type, is the space factor of the winding, or the percentage of the total winding space occupied by copper. The space not occupied by copper is that required for insulation or for ventilating ducts. Small high-voltage transformers have a relatively poor space factor, which grows better as the k. v. a. increases and the voltage rating decreases. While the relation be-

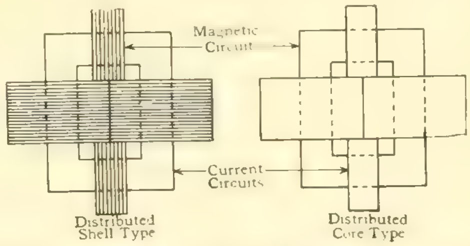


FIG. 3—RELATION BETWEEN THE DISTRIBUTED SHELL AND CORE TYPE TRANSFORMER CONSTRUCTION

tween the space factor of the winding and the most economical type of transformer to meet certain specifications is not obvious, the following explanation will make it more apparent.

A shell type of transformer has a short mean turn of iron, while a core type has a short mean turn of copper. There is a tendency to use the greater amount of the material having the shorter mean turn, because with a given amount of material, the part which has the short mean turn is the most effective in producing an element of large sectional area. The materials are economically disposed when, with a given amount of iron and copper, the sectional area of each is a maximum. This is true because the output of the transformer is a maximum when the product of these areas is a maximum. With the shell type of transformer, since the weight of copper is small, the sectional area is small and the space factor of the copper has a great effect upon the design; that is the winding with a large percentage of insulation is at a disadvantage with this type. On the other hand, with a core type of transformer, whose weight of copper is relatively large, greater constant insulation values do not affect the design so markedly.

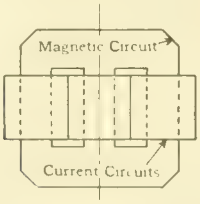


FIG. 4—THREE-PHASE CORE TYPE TRANSFORMER

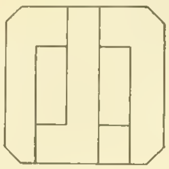


FIG 5—ARRANGEMENT OF THE LAMINATIONS

For each voltage and frequency class, therefore, there is a transformer of a certain output rating, above which the space factor makes the shell type cheaper and below which the core type uses less material.

EFFECT OF CHANGING THE PROPORTIONS OF A TRANSFORMER

A transformer of fixed output and dimensions, was considered in Part IV,* and the losses were varied by changing the densities of working the iron and copper. Since the dimensions of the iron and copper elements remained constant, the weight of these parts did not change. In another case the iron loss only was made to vary by changing the frequency at which the transformer was working.

The problem of design involves varying the losses by changing the dimensions and weight of the magnetic circuit and windings, which means that the cost of the materials also changes. This condition can best be analyzed by the use of equation *14*, Part IV. For this purpose a slight modification of this equation may be made by representing by N the product of the areas of the iron section A_i and of the winding section A_c or,—

$$N = A_i A_c \quad \ldots\ldots (1)$$

*Nov. '17, p. 475.

Substituting this value in equation *14*, Part IV, gives,—

$$P = \frac{B\, I_a\, S_c\, f\, N}{7 \times 10^8} \quad \ldots\ldots (2)$$

Keeping the output, working densities, frequency and winding space factor constant, the value of N in equation *2* becomes constant. This means that the product of the area of the winding space and the area of the iron section is fixed, but that the values of the areas themselves may be variable. This allows a variation in the dimensions of the transformer, as for instance A_c may be large in which case A_i being small, the weight of copper in the transformer would be relatively greater than the weight of iron. On the other hand, A_i might be larger and the transformer would be relatively heavy in iron. Since the energy loss per pound of iron and copper remains constant, the losses will vary as the weights of these materials in the magnetic circuit and windings. In addition to the changes resulting from a variation in the relative values of A_i and A_c, the relative dimensions of the iron and copper sections may be changed. There are, therefore, three main variables* to be taken into account:—

1—The ratio of the area of the iron to the area of the copper section.
2—The ratio of the dimensions of the winding section.
3—The ratio of the dimensions of the iron section.

The distributed shell or core type introduces another variable, which is the ratio of the areas of the two small circuits to the areas of the two larger ones. Also widening of the magnetic circuit introduces a fifth variable into the design, which is the ratio of the widened section to the unwidened part, thus making five variables in the most general case of transformer design.

EFFECT OF CHANGING THE RATIO OF THE AREA OF THE IRON TO THE AREA OF THE COPPER SECTION

This ratio is the most important of the five variables which are involved in the most general case of design, as a small change in its value has a marked affect on the losses and cost. As the area of the iron section increases and that of the copper section decreases, the weight of iron, the iron loss and the cost of the iron increases and the weight of copper, copper loss and cost of copper decreases. If the copper section has a low space factor, that is a small amount of copper, a reduction of the area of the copper section will not mean a large reduction in weight or cost of the copper. Therefore with a low copper space factor the iron section will be smaller and the gross copper section will be larger than with a high copper space factor. The actual value of the variable in a particular case, depends on the relative cost of iron and copper per pound, as well as the insulation clearances or the space factor of the copper section.

*Mr. Charles Fortescue was one of the first to express the losses and the cost of the active material of a transformer in terms of these variables.

EFFECT OF CHANGING THE RATIO OF THE DIMENSIONS OF THE IRON AND COPPER SECTIONS

It is evident that the length of the mean turn of both the iron and the copper elements should be a minimum for a given area of their sections. Thus when the mean length of turn of each element is a minimum, a given number of turns of copper would have a minimum weight and resistance, and the iron circuit would have a minimum amount of material. For example, with the iron section a square, the mean turn of copper would be a minimum for a given area of the iron section, but on the other hand, the mean turn of the iron itself would be greater than if the iron section were rectangular. It is therefore apparent that there is a direct relation between these two variables.

Small changes in these variables, however, have only a slight effect on the design and when their best values have been determined they may thereafter be regarded as constants without appreciable loss; unless there is some other reason for a change in their value, than the question of economy of material or reduction in loss.

RATIO OF THE AREAS OF THE LARGE AND SMALL CIRCUITS WITH THE DISTRIBUTED SHELL AND CORE TYPES

Since the gain by the use of the distributed shell and core types of construction, as compared to the simple forms is not great, slight changes in this variable would not be expected to affect the design materially. When its value has once been determined it may thereafter be considered a constant, even though theoretically it is a variable whose value depends on the ratio of the dimensions of the winding section, which in turn is related to the other design variables.

PERCENTAGE OF WIDENING OF THE MAGNETIC CIRCUIT

The widening of the magnetic circuit may be looked upon as an expedient to reduce the iron loss by reducing the magnetic density in the widened part. The loss in the widened portion will decrease approximately as the square of the increase in area, but the weight of iron in this part will increase by an amount proportional to the increase of the area, so that the iron loss in the widened part will decrease approximately as the percent widening. A similar reduction in iron loss can be secured by increasing the dimensions of the transformer as a whole, in which case the cost would increase at a different rate than when the cost is increased by widening. The relation between these two rates of cost increase is a complicated one. It is found that when a certain widening is reached, it is cheaper to further reduce the iron loss by putting more material into the transformer as a whole than by additional widening. The most economical widening is different for the different types of transformers, being greater for the shell than for the core type.

Another reason for the use of the widened magnetic circuit, is that the exciting current is reduced, partly by putting the joints in the low density part and because ordinarily the exciting current is reduced by the same steps which reduce the iron loss. While theoretically the percentage widening is related to the other design variables, practically it may be considered as a constant after a reasonable value has once been determined upon for some particular case.

METHODS OF DESIGN

There are two fundamental premises from which the design of a transformer may be started. These are as follows:—

1—With the magnetic and current densities fixed, to design a transformer having a minimum cost.
2—With the magnetic and current densities fixed, to design a transformer for which the sum of the losses will be a minimum.

The first premise is to make the cheapest possible design without considering the losses. Because the copper cannot be worked beyond a certain density because of heating, and the iron cannot be operated beyond a definite magnetic density because of saturation of the circuit, there is a limit to the cheapness of a transformer for a given rating. Thus the problem becomes one of designing a transformer with fixed current and magnetic densities. For this case where low losses are not important, it would not be necessary to use either the distributed shell or core types of design, or to widen the magnetic circuit. The proper design for this case will usually be the one whose cost of iron and copper are approximately equal.

To design a transformer for a minimum sum of the losses instead of a minimum cost, with the densities fixed in both cases, the correct design would usually be the one where the iron loss is approximately equal to the copper loss. The designs for the two cases would be identical if the ratio of the cost per pound of iron to the cost per pound of copper is equal to the ratio of the watts lost per pound in each.

When a transformer is designed to have given losses, the problem is not primarily one of fixed densities, because in this case the densities depend on the given losses. For example, if the iron loss is to be small, the iron density must be correspondingly low, and the same condition applies to the copper circuit. Therefore, if the iron and copper densities are low to give small losses, the weights of iron and copper will be correspondingly high and the cost of the transformer will be large. To view this last problem from another angle, suppose a transformer was designed with the magnetic and current densities fixed and for a given equivalent total loss. If this equivalent loss is for example larger than the equivalent loss desired, the magnetic and copper densities must be reduced. If now the relative value of the iron and copper losses is not that desired, they may be varied in the manner described in Part IV. In case the saturation of the magnetic or heating of the copper circuit will not permit the desired relation between the iron and copper losses to be secured, the design must be distorted in order to secure this result. If for example the iron loss is not low enough, the iron section must be made smaller and the copper section larger until the reduced amount of iron will permit the desired iron loss to be secured.

Repulsion and Mutual Inductance of Reactance Coils with the Same Axis

H. B. Dwight

SINCE REACTANCE COILS are sometimes mounted end to end, so as to have the same axis, formulas are desirable for the repulsion and mutual inductance of reactance coils in this position. The values of mutual inductance are useful for determining and correcting the unbalance in voltage which occurs when three coils are mounted close together along the same axis. The values of repulsion are useful in designing the supports of the coils, and in determining how close together the coils may be mounted without danger of damage at times of short circuit. The formulæ here presented refer to cylindrical coils of usual shape, of equal diameter and the same style of winding, and are for coils of unequal, as well as equal, length. The formulas have been specially derived so as to include allowances for the thickness of the coils.

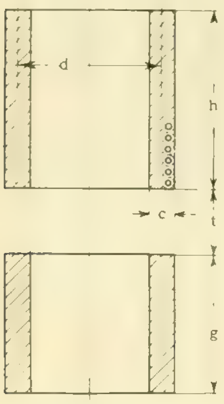


FIG. 1— REACTANCE COILS WITH THE SAME AXIS

Let there be two reactance coils, of lengths g and h, Fig. 1, mounted so as to have the same axis, and separated by a distance t. The dimensions should be measured to the pitch lines of the wire or cable of which the coil is wound. Let the two coils have the same diameter and the same style of winding. Then it is possible to assume a coil of length t placed between them, so as to make one long uniform coil.

The self-inductance of this long coil is,—

$$L_{g+h+t} = L_g + L_h + L_t + 2M_{gh} + 2M_{gt} + 2M_{ht}$$

where M_{gh} is the mutual inductance of the two original coils of length g and h, etc.

$$\text{Also, } L_{g+t} = L_g + L_t + 2M_{gt}$$
$$\text{and, } L_{h+t} = L_h + L_t + 2M_{ht}$$

Eliminating M_{gt} and M_{ht} from these equations, gives,—

$$L_{g+h+t} = 2M_{gh} + L_{g+t} + L_{h+t} - L_t$$

Therefore,

$$M_{gh} = \frac{1}{2}\,(L_{g+h+t} + L_t - L_{g+t} - L_{h+t})^{*} \quad \ldots\ldots\ldots\ldots (1)$$

The number of turns to be used in figuring the four self-inductances will be different in each case, and will be proportional to the length of coil considered. The calculation of formula 1 can be avoided when the coils are of equal length and when a very precise result is not required, by using the curves of mutual inductance, Fig. 2.

The force of repulsion or attraction between two coils carrying current may be calculated from the expression for the mutual inductance of the coils. The force is equal to the differential of the mutual inductance with respect to the distance between the coils, when one unit of current is flowing in each coil, absolute electro-magnetic units being used throughout. This result is derived as follows:—

Let the force in dynes be F, and the currents in the two coils be I_1 and I_2, in abamperes, or absolute electro-magnetic units of current. Let one coil move a short distance ds in time dt. The rate of mechanical working is $F\frac{ds}{dt}$.

This is equal to the rate of electrical working which is,—

$$-I_2 E = -I_1 I_2 \frac{dM}{dt}$$

where E is the e.m.f. generated in the coil by the change

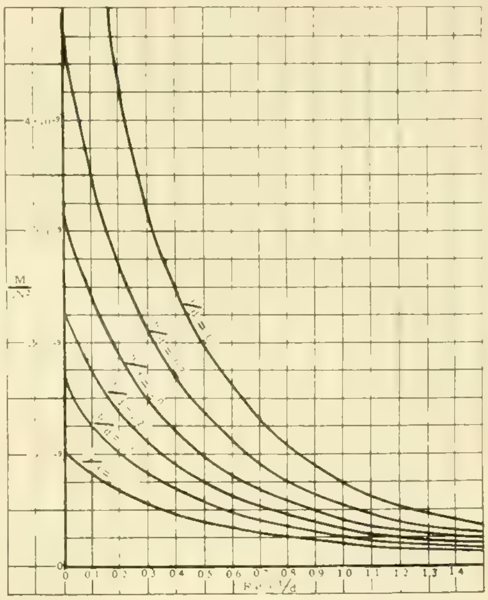


FIG. 2—MUTUAL INDUCTANCE OF REACTANCE COILS IN FIG. 1.

of lines of force through it. Therefore,—

$$F = -I_1 I_2 \frac{dM}{ds} \text{ dynes} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The expression for mutual inductance in equation 1 is readily differentiated, but the parts must be considered separately since it is indeterminate what formula will be used in calculating each part.

By differentiating the formulas for self-inductance of coils, the following method is derived for calculating the force of repulsion or attraction between two coaxial coils of the same diameter and style of winding:—

Find the quantity Q_1 for the four cases when $l = g + h + t,\ t,\ g + t$, *and* $h + t$.

When l is greater than d,—

$$Q_1 = \frac{1}{2}\pi^2 d^2 m^2 \left[1 - \frac{2}{3}\frac{c}{d} + \frac{1}{3}\frac{c^2}{d^2} - \left(\frac{1}{8} + \frac{1}{12}\frac{c^2}{d^2}\right)\frac{d^2}{l^2} + \left(\frac{3}{64} + \frac{7}{64}\frac{c^2}{d^2}\right)\frac{d^4}{l^4} - 0.0211\frac{d^6}{l^6} + 0.0150\frac{d^8}{l^8} - 0.0101\frac{d^{10}}{l^{10}} + 0.0073\frac{d^{12}}{l^{12}}\right] \ldots\ldots\ldots\ldots (3)$$

*See The Bulletin of the Bureau of Standards, Vol. 8, No. 1, by E. B. Rosa and F. W. Grover, p. 72.

When l is less than d and greater than c,—

$$Q_t = \pi d m^2 l \left[\left(\log h \frac{4d}{l} \right) \left(2 + \frac{1}{2}\frac{l^2}{d^2} + \frac{1}{12}\frac{c^2}{d^2} - \frac{3}{32}\frac{l^4}{d^4} \right) - 2 - \frac{\pi}{3}\frac{c}{l} + \frac{5}{24}\frac{c^2}{d^2} + \frac{1}{6}\frac{c^2}{l^2} + \frac{5}{64}\frac{l^4}{d^4} \right] \ldots\ldots\ldots (4)$$

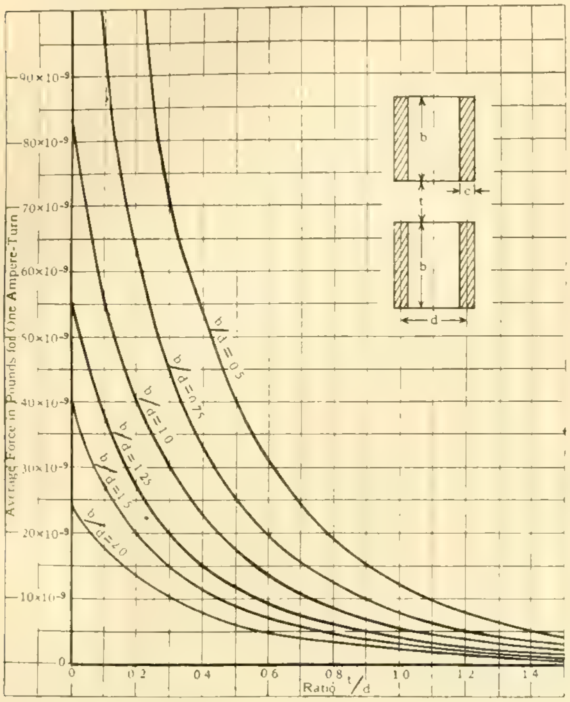


FIG. 3—MECHANICAL FORCE BETWEEN REACTANCE COILS WITH THE SAME AXIS

Avereage force in pounds = F (from curve) $\times I_1 I_2 \times N^2$ $\cos\theta$, where θ is the phase angle between I_1 and I_2 and N is the number of turns per coil.

When l is less than c,—

$$Q_t = \pi d m^2 l \left[\left(\log h \frac{4d}{c} \right) \left(2 + \frac{1}{2}\frac{l^2}{d^2} + \frac{1}{12}\frac{c^2}{d^2} \right) + \frac{2}{3}\frac{l^2}{c^2} \log h \frac{c}{l} - \frac{\pi l}{c} \left(1 + \frac{1}{3}\frac{l^2}{d^2} \right) - 1 + \frac{1}{2}\frac{l^2}{d^2} + \frac{11}{9}\frac{l^2}{c^2} + \frac{43}{144}\frac{c^2}{d^2} + \frac{7}{16}\frac{l^4}{c^2 d^2} + \frac{1}{30}\frac{l^4}{c^4} \right] \ldots\ldots\ldots\ldots (5)$$

Then the effective force in pounds is, —

$$F = \frac{I_1 I_2}{1.45 \times 10^7} (Q_{g+t} + Q_{h+t} - Q_{g+h+t} - Q_t) \text{ pounds} \ldots\ldots (6)$$

where I_1 and I_2 are in amperes.

In the above formulas, the dimensions may all be in inches, or they may all be in centimeters. The quantity m is not the number of turns in a coil, but it is the number of turns per inch of coil when all the dimensions are in inches, and it is the number of turns per centimeter of coil when all the dimensions are in centimeters. Also $\log h \frac{4d}{c}$ (the natural or hyperbolic logarithm of $\frac{4d}{c}$) $= 2.3026 \log_{10} \frac{4d}{c}$.

The values of Q should be calculated with care, as the result of the subtraction is smaller than the values. Neither formula 3 nor 4 is very convergent for $l = d$, at which value of l, $Q = 3.966\ d^2m^2$, when $\frac{c}{d}$ is $\frac{1}{6}$. Formulas 3 to 6 are not suitable for very short coils, such as those of shorter length than indicated in Fig. 3.

The results of the above formulas are plotted in curves in Fig. 3, for various usual shapes of coils, when the two coils are of equal length. Since it is not usually desired to know the repulsion between reactors with very great accuracy, the curves of Fig. 3 can be used for solving problems, thus avoiding the necessity of making the calculations.

The mechanical force between two coils with the same axis is an attraction when the currents in them are in the same direction around the coils, and a repulsion when the currents are in opposite directions around the coils. With alternating currents, the forces, as calculated in this article, are average forces.

The results of the method of calculating the repulsion of reactors given in this article can be compared with a test curve which has been published.* The dimensions of the coils tested are given in Example I of this article, and the curves of calculated and measured repulsions are shown in Fig. 4.

EXAMPLE 1—(See Fig. 4).

Find the average mechanical force acting on each of two coils, placed end to end, as follows:—

Mean diameter of coils	d =	25.53	inches.
Length of coils	g = h = b =	30.87	inches.
Thickness of winding	c =	4.87	inches.
Number of turns per coil	N =	114	turns.
Diameter of conductors		0.408	inches.
Pitch of conductors		0.813	inches.
Air space between coils, from copper to copper		15	inches.
Theoretical separation of coils	t =	14.60	inches.
Current in the coils	$I_1 = I_2 =$	500	amperes

I_1 and I_2 are in phase.

By formula 3,—

$$Q_{g+t} = Q_{h+t} = \frac{9.87}{2} \times 25.53^2 \times \frac{114^2}{30.87^2} \left(1 - 0.1271 + 0.0121 - 0.0404 + 0.0051 - 0.0008 + 0.0001 - \ldots\ldots \right) = 37\,300$$

By Formula (3),

$$Q_{g+h+t} = \frac{9.87}{2} \times 25.53^2 \times \frac{114^2}{30.87^2} \left(1 - 0.1271 + 0.0121 - 0.0143 + 0.0006 - \ldots\ldots \right) = 38\,200$$

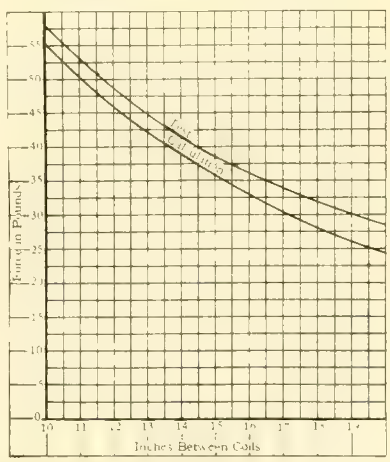


FIG. 4—COMPARISON OF CALCULATED WITH TEST VALUES

By Formula (4),

$$Q_t = \pi \times 25.53 \times \frac{114^2}{30.87^2} \times 14.60 \left(4.193 - 2 - 0.3490 + 0.0076 + 0.0185 + 0.0084 \right) = 30\,000$$

Force in pounds at 500 amperes, by formula 6,—

$$= \frac{500 \times 500}{1.45 \times 10^7} (2 \times 37\,300 - 38\,200 - 30\,000) = 35.7 \text{ pounds.}$$

*"The Mechanical Stresses in Reactance Coils," by W. M. Dann, in the JOURNAL for April, '14, Fig. 8, p. 206.

This result can be obtained approximately by means of Fig. 3, as follows,—

$$\frac{l}{d} = \frac{14.60}{25.53} = 0.572 \qquad \frac{b}{d} = \frac{30.87}{25.53} = 1.21$$

$$F = 11 \times 10^{-9} \times 500^2 \times 114^2 = 36 \textit{ pounds}.$$

EXAMPLE II—

Find, by means of Fig. 2, the mutual inductance of the two coils in Example 1, and the voltage drop in one coil at 60 cycles.

$$M = 0.68 \times 10^{-9} \times 25.53 \times 114^2 = 0.000226 \textit{ henry}.$$

The voltage drop in one coil due to mutual inductance at 500 amperes and 60 cycles is,—

$$2\pi \times 60 \times 0.000226 \times 500 = 43 \textit{ volts}.$$

EXAMPLE III—

Find the total average force exerted on each of three coils placed end to end, the dimensions being the same as in Example 1, and three-phase current of 500 amperes per phase flowing in the coils.

The average force between two of the coils is proportional to the average of the products of the instantaneous values of two alternating currents which are 120 degrees out of phase. It may therefore be calculated the same as the watts which are due to an alternating voltage and current which are out of phase. The average force between the middle coil and an end coil is, therefore, using Fig. 3,—

$$11 \times 10^{-9} \times 500 \times 500 \times \cos 120^\circ \times 114^2 = 18 \textit{ pounds}.$$

For the two end coils,—

$$\frac{l}{d} = \frac{60.07}{25.53} = 2.35$$

The average force on one end coil exerted by the other end coil is, therefore, approximately,—

$$0.5 \times 10^{-9} \times 500 \times 500 \times \cos 120^\circ \times 114^2 = 0.8 \textit{ pounds}.$$

This average force is to be added to the previous value, making the total average force on either end coil approximately 19 pounds.

The average force on the middle coil is zero, since it is subjected to an equal repulsion from each of the end coils. The middle coil is, however, subjected to a momentary force, first in one direction and then in the other, during each cycle. The above forces become much larger under shortcircuit conditions since they increase as the square of the current.

Braking of Electric Motors

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THE PROBLEM of starting and accelerating electric motors has received considerable study. The problem of braking a motor and holding its load is similar, in many respects, to that of starting and accelerating, but the methods used differ. Braking may be accomplished by the use of a friction brake or by dynamic braking. In the first method the stored energy of the revolving armature and the moving load is absorbed by the friction surfaces and dissipated as heat. In the second method it is delivered by the armature as electrical energy, which may be absorbed in an external resistance or returned to the supply circuit.

The stored energy of a revolving armature is given by the formula*:—

$$A = 0.5 \frac{W_1}{g} \omega^2 G^2 \qquad (1)$$

Expressed in ft. lbs. this energy is given by the equation,—

$$A = 0.5 \frac{W_1}{32} \times \left(\frac{r.p.m.}{10}\right)^2 G^2 = \frac{W_1 S^2 G^2}{6400} \qquad (2)$$

The torque required to retard the revolving armature is given by the equation, —

$$T = \frac{W_1 G^2}{g} \times \frac{d\omega}{dt}$$

Where $\frac{d\omega}{dt}$ represents the rate of retardation at any instant. The average rate of retardation in t seconds $= \frac{\omega}{t}$. The average retarding torque then, expressed as a practical formula, is,—

$$T = \frac{W_1 G^2 S}{320 t} \qquad (3)$$

Conversely the time required to stop a motor when the braking force is applied is,—

$$t = \frac{W_1 G^2 S}{320 T} \qquad (4)$$

In applying equations (3) and (4) it should be kept in mind that T is the average braking torque, which is not necessarily equal to the final torque exerted by the brake. A friction brake has a slight time element in setting which causes the braking force to be applied gradually. This time element is a good feature in some applications, such as an elevator and means are sometimes employed to produce it.

The above equations do not take into account the stored energy of the driven load. In the case of a

*In this article the following notation is used throughout:—
A = stored energy of the motor armature in foot-pounds.
B = angle covered by two shoes in radians.
C = shoe width ÷ wheel radius.
D = the stored energy of the hoist drum in foot-pounds.
E = The total stored energy of any system in foot-pounds.
E_L = the line voltage.
E_C = the counter e.m.f. of the motor.
E_T = the voltage at the terminals of the motor.
f = coefficient of friction.
F = the energy absorbed by the hoist mechanism in foot-pounds.
g = acceleration of gravity = 32 (approx.)
G = radius of gyration in feet.
I = the load current of the motor.
I_B = the current in the dynamic braking circuit.
k = a factor depending upon the radius of the hoist drum and the gear reduction between the drum and the motor shaft.
K = a constant depending upon the design of the motor.
L = the stored energy of the load including ropes, counterbalances, etc.
p = pressure in pounds per square inch.
P_1 = the retarding force in pounds required to stop the moving load.
R = the resistance of the motor armature.
R_B = the resistance of the dynamic braking circuit.
S = the full-load speed of the motor in r.p.m.
S_1 = the full-load speed of the shaft on which the brake is applied.
t = the time in seconds required to stop.
T = the torque in pounds at one foot radius.
V = the speed of the load in ft. per min.
W_1 = the weight of the armature in pounds.
W_2 = the weight of hoisted load, including ropes, counterbalances etc.
W_3 = the weight of the unbalanced portion of the load.
ω = the angular velocity of the armature in radians per sec. = r.p.m. ÷ 10 for practical use.
ϕ = the total field flux.

hoist the load moves in a straight line and the stored energy is given by the equation,—

$$E = 0.5\,\frac{W_2}{g}\left(\frac{V}{60}\right)^2$$

Expressed in foot-pounds this is,—

$$Ft.\text{-}lbs. = \frac{W_2 V^2}{230\,000} \quad \ldots\ldots\ldots\ldots (5)$$

Equation (5) gives the energy stored in the load but does not necessarily represent the energy that must be handled by the brake. The latter will be more or less dependent upon whether the load is being hoisted or lowered and upon the time employed in braking. This is evident since a body moving upward is doing work against gravity and will finally come to rest of its own accord. This work done by gravity $= \frac{W_3 V t}{120}$ *ft.-lbs.*, W_3 in this case being the unbalanced load. Then the stored energy that must be handled by the brake in stopping a hoisted load is given by the equation,—

$$L = \frac{W_2 V^2}{230\,000} - \frac{W_3 V t}{120} \quad \ldots\ldots\ldots\ldots (6)$$

The stored energy that must be handled in stopping a descending load is,—

$$L = \frac{W_2 V^2}{230\,000} + \frac{W_3 V t}{120} \quad \ldots\ldots\ldots\ldots (7)$$

The force required at any instant to retard a moving body is given by the equation,— $P = \frac{W}{g}\frac{dv}{dt}$

Where $\frac{dv}{dt}$ = the rate of change of velocity at any instant. If the body is brought to rest in t seconds the average value of $\frac{dv}{dt} = \frac{v}{t}$ Then the average force required to bring the body to rest from a velocity V in time t is $P = \frac{W}{g} \times \frac{v}{t}$. The braking force required to stop a hoisted load is,—

$$P = \frac{W_2}{32} \times \frac{V}{60t} - W_3 \quad \ldots\ldots\ldots\ldots (8)$$

The braking force required to stop a descending load is,—

$$P_1 = \frac{W_2}{32} \times \frac{V}{60t} + W_3 \quad \ldots\ldots\ldots\ldots (9)$$

The above values of P_1 are the forces acting directly on the load. The load is hoisted by a rope passing over a drum which is geared through several reductions to the motor shaft. It is common practice to apply the brake at the motor shaft which runs at a much higher speed than the drum. The torque at the motor shaft is reduced by an amount depending upon the gear reduction. The required braking torque in pounds at one foot radius at the motor shaft is $T = k\,P_1$ where k is a factor depending upon the radius of the hoist drum and the gear reduction between the drum and the motor shaft.

The stored energy of the drum and other moving parts of the hoist mechanism and the friction of the hoist also affect the amount of braking required. In very large hoists the weight of the hoisting ropes may need to be considered. The stored energy of the drum and the friction of the hoist are not easily determined since they vary with different types and builds of hoists. They can best be expressed as a percentage of other larger factors.

The stored energy that must be taken care of in braking in the case of a hoist is,—

$$E = A + L + D - F \quad \ldots\ldots\ldots\ldots (10)$$

Having the total stored energy and the time required to stop, the amount of braking torque may be obtained from the equation,—

$$T = \frac{E \times 60}{t\,\pi\,S_1} \quad \ldots\ldots\ldots\ldots (11)$$

DYNAMIC BRAKING PRINCIPLES

If a motor is driven by the load with its field excited, it will supply energy to the line if the voltage generated by the armature is greater than the line voltage. The voltage which must be applied to the terminals of a direct-current motor is given by the equation,—

$$E_1 = E_c + RI \quad \ldots\ldots\ldots\ldots (12)$$

The counter e.m.f. of the motor is proportional to the field flux $\times$ the speed $\times$ the number of conductors in series. It may be given by the equation,—

$$E_C = K\phi \quad \ldots\ldots\ldots\ldots (13)$$

When a motor running at a speed S is disconnected from the line and the armature short-circuited through a resistance with the field excitation unchanged, the voltage at the terminals of the motor is given by the equation,—

$$E_T = E_C - I_B R \quad \ldots\ldots\ldots\ldots (14)$$

The rate of dissipating energy is,—

$$I^2_B\,R + I^2_B\,R_B \quad \ldots\ldots\ldots\ldots (15)$$

which shows that the kinetic energy of the revolving armature and the moving load must be dissipated as heat by the dynamic braking resistance and the motor windings. Hence, a motor which is stopped frequently by dynamic braking must have greater capacity than would be required if it had only to accelerate and drive the load.

The current that will flow during dynamic braking is given by the equation,—

$$I_B = \frac{E_C}{R_B + R}$$

Since the braking torque is proportional to the current it follows that the braking torque depends upon the counter e.m.f. of the motor and the ohmic value of the dynamic braking resistance. As the motor slows down, the counter e.m.f. and current fall off and consequently the braking reduces, as the motor reaches a low speed. For this reason it is impossible to bring the motor to a complete stop with dynamic braking. Fig. 1 shows the case of a constant speed motor retarded by dynamic braking.*

The conditions are somewhat different in the case of an adjustable speed motor operating with weakened field. Since the counter e.m.f. of the motor depends upon the field flux the braking current will be increased if the field is strengthened at the time the armature is disconnected from the line. The case of a 400 to 1600 r.p.m. motor in which the field current was brought to the 400 r.p.m. value when the dynamic braking circuit

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*See article on "Industrial Controllers—IX—Starting Characteristics of Motors with Different Methods of Control" by H. D. James in the JOURNAL for Sept. '17, p. 349.

was closed is shown in Fig. 2. Due to the inductance of the field circuit, the flux does not build up instantly while the motor begins to slow down as soon as the dynamic braking circuit is closed. The result is that the counter e.m.f. does not reach as high a value as it would if the field built up instantly. The combined

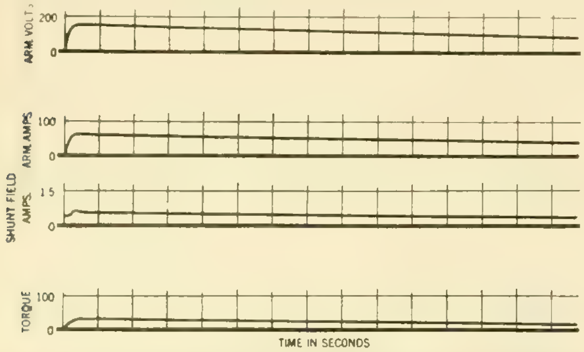


FIG. 1—STARTING TESTS OF A 15 HP, 1600 R.P.M. MOTOR BELTED TO A 50 KW GENERATOR, WITH NO LOAD ON THE GENERATOR

Showing decreasing torque with decreasing speed causes considerable drift before the dynamic braking finally brings the motor to rest.

condition is that the braking torque is quite constant down to a speed where the friction of the load will bring the motor to rest.

A very different condition is obtained where a series motor, running at high speed with weak field, is disconnected from the line and then reconnected so as to build up its own field. The series field winding has a relatively low inductance so that the field current and flux build up very quickly. The result is a severe cumulative braking action in which the motor voltage and dynamic braking current may become so high as to cause the motor to flash over.

The Dynamic Braking Resistance must have an ohmic value such as to allow just the proper current to flow and must be capable of absorbing and radiating as heat the stored energy of the motor and load. The resistance must limit the current to a value that the motor can safely commutate and that will not subject the motor or load to undue shock. In some applications, such as an elevator, the latter point should receive particular attention.

Equation (2) for the stored energy of a revolving armature may be written,—

$$\text{Watt seconds} = \frac{W\ S^2\ G^2}{1717} \qquad (16)$$

If the motor is brought to rest in t seconds, the rate of dissipating energy is,—

$$\text{Watts} = \frac{W\ S^2\ G^2}{1717\ t} \qquad (17)$$

This is an average value and the rate of dissipating energy is much higher at the beginning of the cycle than at the close. Hence, if a resistor has considerable thermal capacity it can absorb energy at a high rate at the start and radiate it at the end of the cycle.

APPLICATIONS OF DYNAMIC BRAKING

Fixed Dynamic Braking—Figs. 1 and 2 show that the braking torque finally reaches a low value and the motor will drift for a considerable time. In the case of a motor driving a load where an exact stopping point is not necessary, such as a machine tool, the friction of the machinery will bring the motor to rest in a sufficiently short time after the dynamic brake becomes ineffective.

The braking connections for an adjustable speed machine tool motor are shown in Fig. 3. The operating coil of the field relay *FR* is connected in the main circuit so as to short-circuit the field resistance in starting and in the dynamic braking circuit so as to give a full field during dynamic braking. When the motor has come to rest the dynamic braking current has reduced to zero and the relay drops out and reinserts the field resistance so as to reduce the field current when the motor is idle.

In a number of steel mill applications such as a screw down, manipulator fingers, etc., where a quick stop at a definite point is required, it is common practice to employ a friction brake in addition to dynamic braking. The friction brake takes care of a portion of the stored energy of the armature and load and prevents drifting. A very quick and positive stop can be obtained in this way, since the dynamic braking is a maximum at the first instant of application while the friction brake has a slight time element in setting, but exerts its maximum torque after the dynamic braking has begun to reduce.

Dynamic braking is often used to bring the motor from full speed to a fixed lower speed. In this case the dynamic braking resistance is connected in parallel

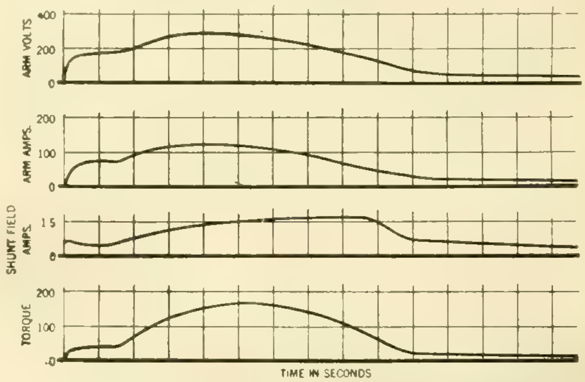
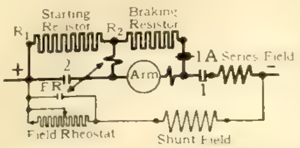


FIG. 2—EFFECT OF FIELD VARIATION ON DYNAMIC BRAKING

Made with a 15 hp, 400-1600 r.p.m. motor belted to a 50 kw generator with no load on the generator. When the motor was operating at 1600 r.p.m. the armature was disconnected from the line and connected to a resistance to give dynamic braking. At the same time the motor field rheostat was short-circuited, strengthening the field to the 400 r.p.m. value. The curves show that the field built up faster than the speed decreased so that the armature voltage at first increased and then remained practically constant for a considerable period. A strong dynamic brake was thus maintained until the motor speed was quite low so that it could be easily stopped by friction or a mechanical brake.

with the armature which is connected to the line in series with the starting resistance. The voltage drop in the series resistance reduces the voltage at the motor terminals to a value lower than the counter e.m.f., which forces current through the parallel resistance. The motor will quickly come to a speed corresponding to the reduced terminal voltage, its value depending

upon the values of the series and parallel resistances. The connections of a motor and controller embodying this feature are shown in Fig. 4. A typical application is that of the skip hoist for a blast furnace. Here the buckets or skips must be hoisted at a high speed but must be stopped very accurately over the mouth of the furnace. To accomplish this, the slow-down connections are automatically made at certain points in the travel of the skip and the speed reduced to such a value that when the motor is disconnected from the line and the friction brake applied, the skip will come to an immediate stop. The same scheme is used for bringing an elevator car to rest, except that in this case the point at which slowdown and stop occur are controlled by the operator.



SEQUENCE OF CONTACTORS

Con.	[illegible]	Run		Brk
1		O	O	
2			O	
1A	O			O
FR		O		O

FIG. 3—CONNECTIONS FOR AN ADJUSTABLE SPEED MOTOR

Showing method of obtaining full field during starting and dynamic braking.

Adjustable Dynamic Braking—Dynamic braking is frequently used in connection with series motors on unbalanced hoists for lowering the load. It is usually necessary to provide for driving the load downward if it is not heavy enough to overcome the friction of the hoist mechanism and to limit the speed in the case of heavy loads. It is desirable also to adjust the speed to suit the conditions.

In lowering, the series field of the motor is connected across the line in series with a resistance. A resistance is also connected in series with the armature. The motor connected in this manner is virtually a shunt machine with the speed varied by a combination of armature and field control. While lowering, the motor acts as a generator and excites its own field. The lowering speed may be changed by adjusting the resistance in either the armature or field circuit, or both. A friction brake is required to hold the load in the *off* position of the controller. A series wound brake should be used with its operating coil in series with the field. Then if the motor loses its field from any cause and tends to speed up, the brake will set and hold the load. A typical application of this form of braking is that of a crane hoist.

DYNAMIC BRAKING OF ALTERNATING-CURRENT MOTORS

Dynamic braking is not as easy to apply to alternating-current as to direct-current motors. An induction motor has its exciting current in the same windings as the energy current. Hence, it loses its excitation when the motor is disconnected from the line and dynamic braking cannot be obtained. It is possible to excite the primary with direct current and connect the secondary to a resistance. This is sometimes done, but is limited to applications where direct-current is available. It is also objectionable, due to complications in the control.

In some cases the motor is provided with two sets of windings with a different number of poles. For example, a motor may be wound for 6 and 18 poles. If when the motor is running on the 6-pole or high speed winding it is changed over so as to have the 18 pole winding connected to the line, the rotor will then be running very much above synchronous speed and will act as a generator and supply energy to the line. This generator action will slow the motor down to the lower synchronous speed. This scheme is satisfactory for elevators, skip hoists, etc., where the slowdown action is necessary, but requires a rather expensive motor and controller.

ADVANTAGES AND DISADVANTAGES OF DYNAMIC BRAKING

It has been shown that while dynamic braking does not eliminate the use of a friction brake, it has some very distinct advantages over the friction brake for reducing the speed of a motor.

Advantages—

1—The stored energy of the armature is largely dissipated in an external resistance which may be so located as not to affect the motor. In the case of a friction brake this energy must be handled by the brake shoes and wheel which are close to the motor.

2—A quicker stop can be made with dynamic braking due to the time element of the friction brake in setting. The quickest stop however can be made with a combination of the two, as previously pointed out.

3—The kinetic energy of the revolving armature is delivered directly to an external circuit and does not have to be transmitted through the shaft to the brake wheel, thus relieving the shaft of considerable strain.

4—In cases where an accurate stop is not necessary, the equipment for dynamic braking takes up less room, and will have a lower maintenance cost than a friction brake.

5—In cases where a friction brake is necessary to hold the load, it is desirable to use dynamic braking for slowing down. This relieves the friction brake of much wear and tear and consequent expense in upkeep.

Disadvantages—

1—The motor cannot be brought to a complete stop unless the driven load has considerable friction.

2—Dynamic braking cannot be obtained in case of voltage failure without the use of a series winding.

3—A controller for dynamic braking requires an additional contact and resistance which adds to the cost.

4—If the motor is stopped very frequently by dynamic braking, its capacity must be greater to take care of the heating.

5—Dynamic braking is not generally applicable to alternating-current motors.

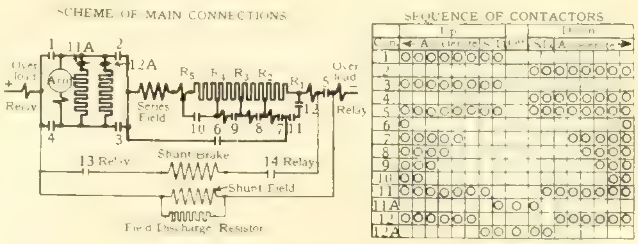


FIG. 4—CONNECTIONS OF AN ADJUSTABLE SPEED MOTOR

Showing series and parallel resistors for slowing down the motor by dynamic braking.

FRICTION BRAKES

Although dynamic braking has relieved the friction brake of much of its most severe duty, and is even eliminating it in some cases, it is still an important element in many motor installations. In designing a brake,

or in selecting one for a particular installation, the following points should receive primary consideration:—

The Brake Shoe Linings— The material used for brake shoe linings should have a constant coefficient of friction over a wide range of pressure and speed and should not be affected by moisture or oil that may get on the brake wheel. It should be a good conductor of heat and the temperature should not affect the coefficient of friction. A fabricated material of asbestos and rubber through which a number of copper wires have been woven has been found to give the best results in practice. Cast iron shoes bearing directly on the cast wheel have been found to be ideal for conducting the heat from the wheel, but are open to the objection that when the face has worn to a certain point the whole shoe must be replaced. There is also more wear on the wheel than when a shoe lined by a suitable friction material is used. If a lined shoe is used, a spare set may be kept on hand and when the linings of a brake wear down, the spare shoes may be put in and the worn shoes relined.

Method of Applying the Pressure to the Brake Shoes— When a brake sets the braking torque should be applied positively and uniformly. In some early types of brakes the pressure was applied by a weight which was lifted by the magnet when the brake was released. The weight in falling set the brake. With such an arrangement the kinetic energy of the moving weight caused a high pressure to be applied to the shoes at the first instant of application, with a corresponding excessive torque. A brake should be designed so that the inertia of the moving parts does not produce this excessive pressure on the shoes. The brake shown in Fig. 5 has the moving arm slotted at the fulcrum so that, as the magnet armature moves out, it can slightly over-travel without increasing the shoe pressure, which is positively applied by the compression springs. The value of the retarding torque is adjusted by means of the handle nut which is held in place by a locking nut.

Adjustment for Wear— Some adjustment for the wear of the shoe linings is necessary and the work done by the magnet must be kept as near constant as possible. Adjustments of this kind should be simple and easily accessible. The adjustment should not be such that, if neglected, the brake will fail to hold its full rated torque. A brake that apparently operates all right, but gradually loses its braking power through wear, is a menace since it may fail to hold at a critical time. The brake shown in Fig. 5 is so arranged that, if adjustment for shoe wear is neglected, in no case will it fail to set and hold its load.

Mechanical Parts— The mechanical design of a brake should receive careful consideration, since all other features depend upon the rigidity and arrangement of the mechanical structure. The parts should be as light as is consistent with strength and rigidity. Bearing pins, where there is any considerable motion, should be designed so as to have as little friction as possible and have ample wearing surfaces. Since the brake is the ultimate safety device in many installations, the fibre stresses in the materials should be kept well within safe limits. It is desirable that the general design be such that the same brake can be equipped with either a direct-current or an alternating-current magnet. A direct-current magnet is inherently more effective on short strokes while the alternating-current magnet is more effective when operating with a long stroke. A very good compromise can be made by carefully proportioning the levers and selecting the proper location of pin centers. Figs. 5 and 6 show alternating-current and direct-current brakes which are similar except for the magnet parts.

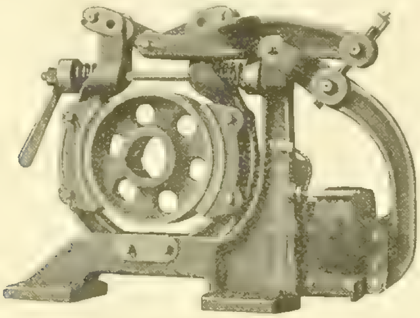


FIG. 5—ALTERNATING-CURRENT MAGNET-OPERATED BRAKE

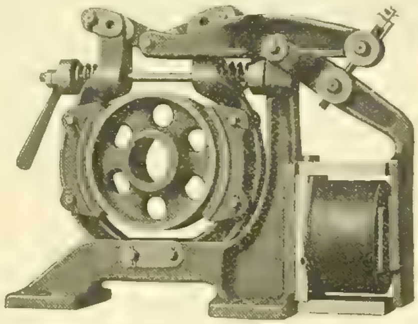


FIG. 6—DIRECT-CURRENT MAGNET-OPERATED BRAKE

When the magnet is energized the spring pressure on the shoes is released leaving the wheel free to turn. When the voltage is cut off from the motor and brake magnet, the spring pressure is applied to the brake shoes.

Direct-current Magnets— There are two general types of magnets for brakes, namely the armature and the plunger type. The plunger type is open to the objection that the plunger moves inside of the coil and must be guided to prevent damage to the insulation. The armature magnet, shown in Fig. 5 has the operating coil held on a stationary core, the end of which forms a pole and attracts the armature. This type, has same distinct mechanical advantages for brake work.

1—No moving parts inside of the coil or winding to damage the insulation.

2—No guides required.

3—No danger of sticking due to the plunger not being properly guided.

4—The coil is easily removed for repairs.

Magnets with an iron housing to enclose the coil usually have higher magnetic leakage than an open type of magnet. Better radiation of heat can be secured if the coil is not enclosed. There is no advantage in enclosing the coil if the winding is impregnated as a protection against ordinary moisture, oil, etc.

The material should have as high a magnetic permeability as possible, although this is not as important in the case of a magnet having a long air-gap as it is in the case of rotating machinery where the air-gap is relatively short. The size of a brake magnet is determined by the pull to be exerted when the brake shoes are set and the air-gap of the magnet is open. At this point practically all of the ampere-turns are used in the air-gap so that the material of the magnet can be selected on the basis of its availability and cost rather than its magnetic properties. If however there are leakage paths that are comparable with the main air-gap in length, the iron may become saturated due to magnetic leakage.

A brake magnet should be large enough to release the shoes quickly and positively when the coil is energized. In general, direct-current brake magnet coils are wound with a comparatively few turns of heavy wire and are connected in series with the motor armature. There are several advantages of connecting the magnet coil in series with the armature:—

1—Coils have low inductance, resulting in quick action.

2—When used with series motors, danger of over-speeding is reduced, since the reduction of current incident to high speed will cause the brake to set.

3—In the case of hoist motors lifting unbalanced loads, the series brake has the advantage that, if the armature circuit should open, the brake will set and hold the load.

4—A series coil has a low voltage across the terminals so that insulation break downs between turns are infrequent. A coil of a few turns of heavy copper can have insulation that will stand considerable overheating without serious injury.

A series-wound brake magnet should have enough turns to release the shoes positively on the first point of the controller. Since this current may be 50 percent of full load, it is necessary that the brakes release at a value safely below this. The coil must radiate the heat produced by the full-load current of the motor and should therefore have the same current rating as the motor with which it is used. The holding torque for which the brake may be set depends upon the ampere-turns available for closing the magnet at the instant of starting the motor. For this reason a brake used with a controller which passes 100 percent of full-load current on the first point could be set for a higher torque rating than if it were used with a controller that only passed 50 percent current. The brake coil could be the same in both cases since the heating is based on full-load current. In many cases a smaller brake could be used for certain applications if it were known definitely that a high current peak was obtained in starting. The rating of the brake would then be limited by mechanical stresses instead of the heating of the magnet.

Shunt-wound magnets are used where the motor current passes through a low value or reverses during some point in the cycle or where a drift point is wanted. The use of a drift point on the controller is to allow the load to coast before applying the brake. If a shunt coil is necessary, it should be wound for a relatively low voltage and connected to the line with a resistance in series. A discharge resistance should be provided to prevent the inductive kick on opening the circuit from breaking down the insulation.

Alternating-current Magnets—The armature type of magnet with an open construction has the same advantages for alternating-current as for direct-current. If a shaded pole face is used it is desirable that it be kept outside of the operating coil. While the same general laws, governing the magnetic flux and exciting current, hold for alternating-current as for direct-current magnets, the alternating-current magnet presents many problems and difficulties that are not encountered in direct-current work. The alternating character of the flux make a laminated structure necessary, to reduce the heating from eddy currents. At the zero flux points there is no force of attraction between the armature and the pole face.* Therefore, if the magnet is to be connected to a single-phase circuit it is necessary to put a short-circuited winding or shading coil around a portion of the pole face. Experience has proved that correct proportioning of electric and magnetic circuits and

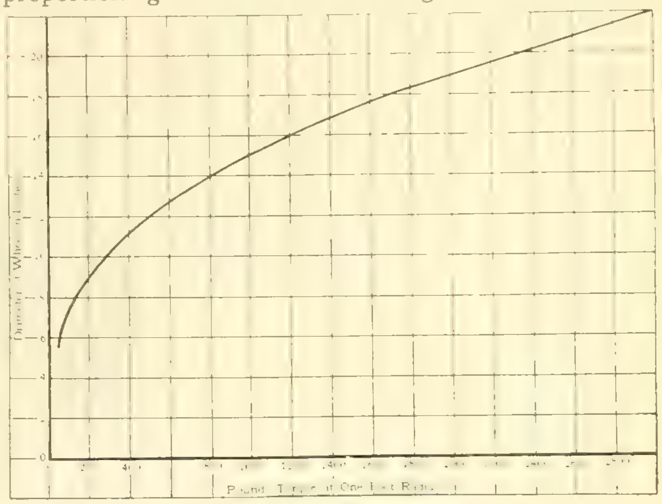


FIG. 7—RELATION OF TORQUE AND WHEEL DIAMETER OF A MAGNET-OPERATED BRAKE

careful design of the shading coil are not all that is necessary. Much depends upon the mechanical structure, method of mounting and arrangement of parts. It has been found that certain constructions, while successful under certain conditions or in certain sizes, may be very noisy when used under other conditions, or built in larger sizes.

Alternating-current brake magnets may be built polyphase as well as single-phase. In a polyphase magnet there is always a magnetic flux in two or more of the poles so that the total pull never becomes zero. However, if the construction is not right there will be a blow at the pole face in which the zero flux does occur, due to local pulling away of the armature at that point. A heavy armature with considerable inertia is less likely to chatter than one that is light. For small brakes a single-phase magnet is preferable because more pull can be obtained for a given weight of iron. The single-phase circuit is also advantageous from the control

*See article on "Shading Coils for Single-Phase Magnets" by Mr. R. T. Kintzing in the JOURNAL for Sept. '15 p. 407.

standpoint. For large sizes the polyphase magnet is better.

The care used in assembling an alternating-current magnet has much to do with its successful operation. A close fit between the armature and pole face is necessary to get a good distribution of flux and a quiet pull and when properly designed and built the alternating-current magnet gives good results.

Diameter of brake wheels—In designing friction brakes, it is important that the brake wheels be of the correct diameter. The correct wheel diameter for a brake to hold a given torque is given by the formula,—

$$D = C_1 \sqrt{Torque} \quad \ldots\ldots\ldots\ldots (18)$$

$$C_1 = 24 \sqrt{\frac{1}{\mu B C_2 \times l \times p}} = a\ constant \quad \ldots\ldots (19)$$

A curve plotted from the above equation is shown in Fig. 7. Knowing the torque the brake is required to hold, the proper wheel diameter is read from the curve. In practice, the wheel diameters are sometimes limited by the distance from the center of the wheel to the base. It is always desirable to have this distance equal to or smaller than the corresponding dimension on the motor with which the brake is to be used.

APPLICATION OF BRAKES

If all the conditions under which a brake is to work are known, it is possible to select a brake to do the required work, using the formulæ given in the first part of this article. However, since in the majority of cases the data is not all available, it is desirable to have some arbitrary basis on which to apply a brake. Brakes are frequently applied as full-torque or half-torque brakes. A full-torque brake is one which when set exerts a retarding torque equal to the full-load torque of the motor. A half-torque brake exerts half of the above torque. The torque of any motor is measured in pounds at one foot radius and may be obtained from the formula,—

$$T = \frac{Hp \times 5252}{S}$$

Full-torque brakes are used where a quick stop and considerable holding is required. On crane hoists it is good practice to put a full-torque brake on the motor shaft and a half-torque brake on the counter shaft of the first gear reduction. These brakes have their coils connected in series with motor armature. The brakes in this case help retard the motor and load and must hold the heaviest load that will be handled by the crane.

Brakes for mill floor service such as manipulators, screw downs, lift tables, etc. are usually applied on a full-torque basis. In these installations, the service is very frequent and accurate stops are required. Dynamic braking is usually used in addition to the friction brake. Series braking coils should be used to insure fast operation. The energy of the motor armature comprises the greatest part of the load.

Brakes used for elevators, skip hoists, bell hoists, etc., are chiefly for the purpose of making the final stop and holding the load. Full-torque or half-torque brakes may be used, depending upon the conditions. Shunt brakes are usually employed due to the nature of the load current which often reaches a low value or may be regenerative. In alternating-current installations, the brake usually both has to retard and hold the load, since dynamic braking is not available.

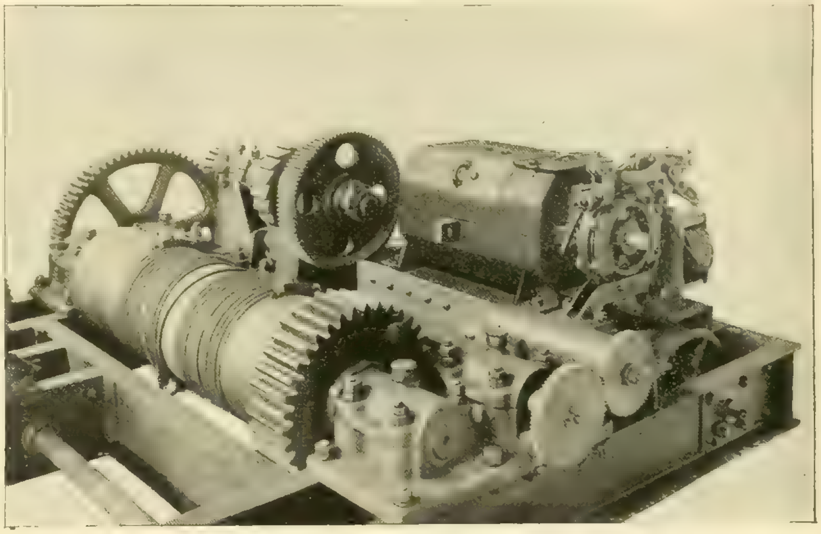


FIG. 8 CRANE TROLLEY
Showing direct-current magnet-operated brake mounted on the direct-current motor.

In a number of applications such as reversing planers, bucket conveyors, etc., brakes are used to stop the moving load in case of emergency. This corresponds to very light service as far as the brake shoes are concerned, but means continuous duty for the magnet winding. Shunt coils are used and are de-energized only in case of failure of voltage or other emergency. Full-torque or half-torque brakes may be used depending upon how quick a stop is required and the load the brake is required to hold.

Industrial Controllers-XVII

Mine Hoists

H. D. James

MINE HOISTS may be divided into two general classes; those for coal mines and for metal mines the essential difference being that coal mines are shallow and the metal mines deep.* Coal mining practice differs in the anthracite and bituminous fields, and the practice varies in different states. In general, hoists for coal mines run from 250 to 1000 horse-power. In metal mines, the motor may reach double the size of that for coal mines. In addition to the main hoists, small hoists are frequently put in for handling men and supplies. These hoists may be so small that the ordinary form of drum controller may be used.**

The large controllers may be divided into three classes:

1—Contactor Controllers.
2—Liquid Controllers.
3—Voltage Controllers.

Most mine hoists are operated from alternating-current supply lines and therefore use alternating-current slip ring motors, either to drive the hoist directly or through a motor-generator flywheel set to supply direct-current to the hoist motor. In some cases where direct-current power is available, the direct-current motor which operates the hoist is controlled directly from the supply lines.

FIG. 1 HOISTING ROOM FOR VOLTAGE CONTROL EQUIPMENT

Showing the flywheel motor-generator set to the right, the liquid regulator in the center and the control panel at the left. Magnetic contactors are used for varying the strength of the generator field.

CONTACTOR CONTROL

This form of control has been used almost entirely for the smaller motors and also for some of the larger motors up to approximately 1000 horse-power. It is much more durable than the drum controller for small motors and is often preferred, although the first cost is greater. The method of control is illustrated in Fig. 2. The drum type master switch causes the motor to operate in either the hoisting or lowering direction and by changing the position of the handle, the speed of the motor may be changed.† Ordinarily, a mine hoist is used for the purpose of hoisting material out of the mine. It is therefore operated normally under load conditions and a rheostatic control of this kind gives satisfactory operation.† In the off position of the controller, a mechanical brake is applied for stopping the hoist and holding it securely at the landing. This brake is often released by an electro-magnet, which is de-energized in the off position of the controller and applies the brake.

One of these controllers built for a 2200 volt primary and a low voltage secondary is shown in Fig. 3. The primary contactors are provided with large magnetic blowouts to take care of the high voltage. The secondary voltage of an induction motor is determined by the design and is independent of the primary voltage. It is customary to wind the secondary of these motors so that the standard low voltage contactors can be used. The primary may be wound for 220, 440, 550 or 2200 volts. For the larger hoists, a 2200 primary is desirable in order to keep the current small and reduce the size of primary leads.

When the empty cage is at the top of the hoist and the loaded cage at the bottom, the motor must lift not only the load in the cage, but also the total weight of the rope between the drum and cage. The weight of the two cages usually balances. After the load is started, the rope on the hoisting side becomes shorter and the rope on the lowering side longer, so that the work done by the motor is gradually decreased.‡ In order to assist the motor in starting the load from the bottom, one end of the drum is frequently coned so that the rope is wound on a small diameter at the start, Fig. 7. This works out very well for short travels where the

*See article on "Control for Mine Hoists" by Graham Bright in the JOURNAL, for December, 1914, p. 704.

**Drum controllers were illustrated in the Feb. 1917 issue of the JOURNAL, pp. 55-57, Figs. 5 to 9. Their principal advantage is cheapness and compactness, and where the duty is light, they are very satisfactory.

†The speed-torque curves for this method of control are shown in the JOURNAL, for April 1917, p 152. These curves show that the speed of the motor depends upon the load.

‡This is illustrated by the torque curve, Fig. 6, p. 280 in the JOURNAL, for July 1917.

rope can be wound upon the drum in a single layer. For deep mine hoists, the rope is wound back and forth across the face of the drum in layers, which makes it necessary to use a cylindrical drum instead of a cone, so that in deep mine hoisting the load starts with maximum torque.

In bringing the motor to rest, it is sometimes customary to reverse the primary of the motor for a short period of time. This reversing of the motor is known as "plugging." It results in a high secondary voltage. If the motor is running at full speed, the slip of the motor will approximate 200 percent and the secondary voltage will be double the voltage obtained when the motor is started from rest. If plugging is to be practiced, the secondary control and the insulation of the motor windings should be arranged for this higher voltage. The operator must be careful to turn the controller to the off position when the motor comes to rest after plugging; otherwise, the direction of rotation will be reversed and an accident may result.

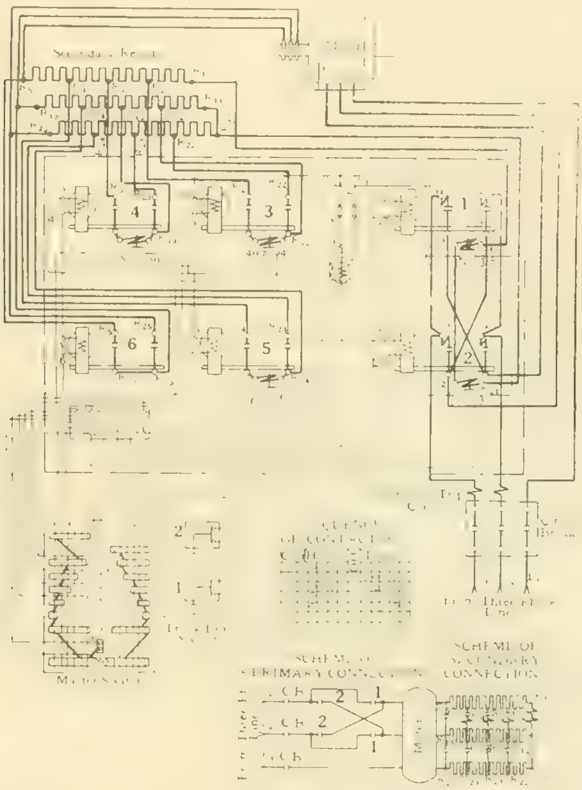


FIG. 2—DIAGRAM OF CONNECTIONS FOR CONTACTOR CONTROLLER

This controller consists of two primary contactors *1* and *2* for the purpose of connecting the primary of the motor to the line to give the proper direction of rotation. Four secondary contactors are controlled by current limit relays. These secondary contactors automatically short-circuit the resistor in the secondary circuit of the motor during acceleration. The primary and secondary contactors are controlled by a drum-type master switch. Two track limit switches automatically stop the hoist at either limit of travel. The motor is protected by a three-pole circuit breaker in the supply line.

The present development of the art has not produced a method for obtaining dynamic braking for alternating-current motors, which is applicable to general hoisting requirements. Dynamic braking can be obtained as explained in the preceding article,* by connecting the primary of the motor to a direct-current source of power. This adds some complication which has prevented its general use.

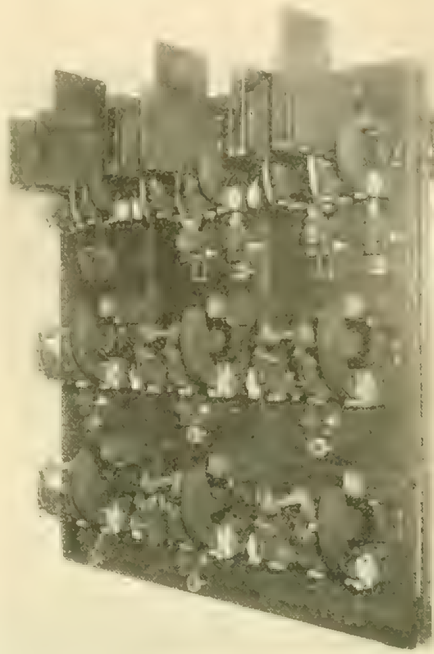


FIG. 3—CONTACTOR CONTROL FOR AN ALTERNATING CURRENT 2200 VOLT MOTOR

Three two-pole contactors are used to control the primary of the motor. One contactor is used for hoisting; a second contactor for lowering, and a third contactor operates for each direction of hoist, acting as an additional safety feature to insure the opening of the motor circuit in case of accident to either of the directional contactors. Six two-pole contactors are used in the secondary circuit. The acceleration is controlled by current limit relays.

A direct-current controller for an automatic mine hoist, using a 600 horse-power, direct-current motor is shown in Fig. 4. The hoist is operated in much the same way as a skip hoist or elevator. After the motor is started, the load is hoisted to the proper level, automatically slowed down, stopped and the load discharged. The speed of this hoist is 500 ft. per min. Up to the present, such an arrangement has not been installed for

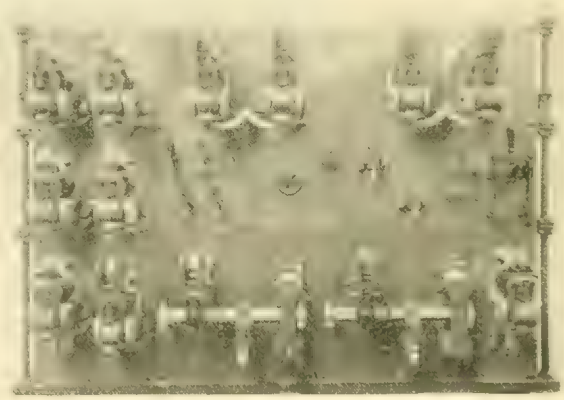


FIG. 4—CONTACTOR PANEL FOR A DIRECT-CURRENT AUTOMATIC HOIST

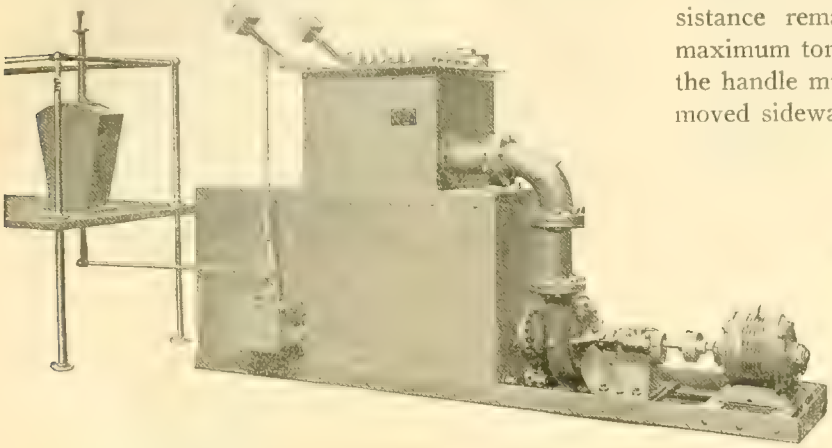
The contactors at the top of the panel, at the right, control the direction of rotation and have a mechanical interlock which prevents one switch from closing before the other directional switch is opened. At the bottom of the panel are two contactors with back contacts for slowing down the hoist automatically. The other contactors are used for short-circuiting sections of resistors.

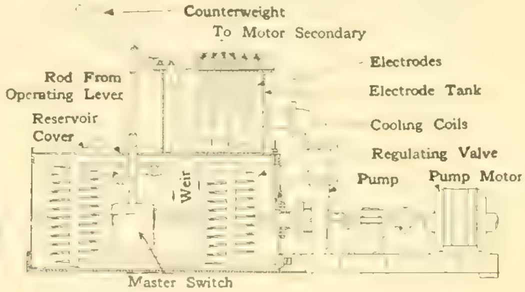
*In the JOURNAL for April 1918, p. 110.

use with alternating-current motors. The contactor type of rheostatic control is preferred in some localities to the liquid controller, even for large size motors.

LIQUID CONTROLLERS

The liquid controller differs from the contactor control in the secondary circuit of the motor only. Both controls use contactors for the primary. The secondary of the motor in this form is connected to a set of electrodes emersed in a solution of water and soda. A cross-section of this control is shown in Fig. 6 and a general view in Fig. 5. The master switch, on the side of the tank, controls the primary contactor and the weir is so arranged that the water level in the electrode tank is at a minimum in the central or off position. The size of this weir is designed so that the electrode tank will empty as fast as the weir is lowered. If, however, the weir is quickly moved to its upward position, it will take from 10 to 15 seconds to fill the upper tank, allowing a suitable time for the motor to accelerate. When the tank is full the secondary of the motor is practically short-circuited, so that the motor runs at approximately full speed. In the reservoir tank underneath the electrode tank is located a system of cooling coils. Water is pumped from this lower tank to the upper tank continuously, causing a circulation around the cooling coils. The height of water in the upper tank is controlled by the height of the weir. The pump is driven by a small induction motor.





FIGS. 5 AND 6—LIQUID RHEOSTAT WITH *H*-SLOT DEVICE

The upper tank contains the electrodes which are connected to the secondary of the motor. The lower tank is a reservoir for the electrolyte and contains the cooling coils. The water is pumped from the lower tank to the upper tank continuously and the height of the electrolyte in the upper tank is determined by the position of the weir. The same levers which raise and lower the weir operate the master switch, which is located on the outside of the reservoir tank. Adjustable stops are provided on the H-slot for regulating the depth of the slot for plugging.

An ingenious arrangement of operating levers is illustrated in Fig. 8. This consists of a floor stand having a slot similar to the letter H, one of each of the opposite sides being short. The long sides of the H are for normal operation. If the operator wishes to plug his motor, he moves the handle back in the same slot, passing through the central position into the short side of the slot, which limits the handle so that sufficient resistance remains in the secondary circuit to give the maximum torque. To pass from one slot to the other, the handle must be brought to the central position and moved sideways.

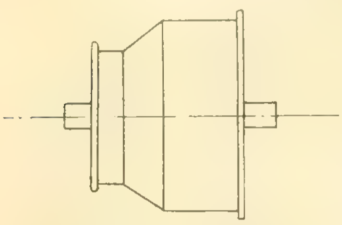


FIG. 7—CONED DRUM

The hoist rope starts winding on the small diameter of the drum. As hoisting progresses, it is wrapped around the coned portion of the drum and thence on to the large diameter portion.

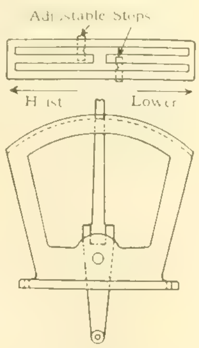


FIG. 8—SINGLE LEVER *H*-SLOT DEVICE

Compared with the contactor control, the liquid controller has the following advantages:—

Simplicity—There are no electrical connections to get out of order, the only renewals being the addition of fresh water from time to time to replace that lost through evaporation or steaming. Fresh water is all that is required, as the soda in the solution remains constant.

Large thermal capacity—The large mass of water will absorb a considerable amount of heat, so that for short intervals of time a large amount of energy can be dissipated.

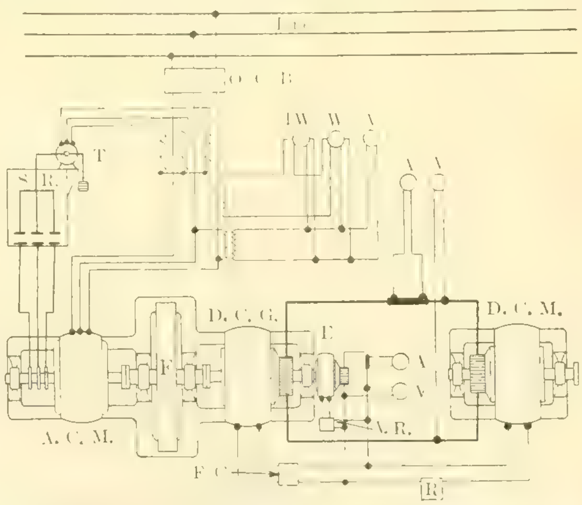


FIG. 9—DIAGRAM OF CONNECTIONS OF EQUALIZER FLYWHEEL HOISTING SET

A.C.M.—wound-secondary induction motor; *F*—flywheel; *D.C.G.*—separately-excited direct-current generator; *E*—exciter; *D.C.M.*—separately-excited direct-current motor; *S.R.*—automatic liquid slip regulator; *T*—torque motor for slip regulator; *O. C. B.*—oil circuit-breaker; *F. C.*—reversing field controller for generator; *R*—rheostat for motor field; *V.R.*—voltage regulator for exciter; *A*—ammeter; *V*—voltmeter; *W*—watthour meter; *I.W.*—integrating wattmeter.

Overload capacity—If energy is accumulated in the rheostat faster than it can be radiated or carried off by the cooling water, steam is formed absorbing the surplus energy.

No definite control steps exist in this form of controller. It is possible, therefore, to adjust the motor for any desired speed.

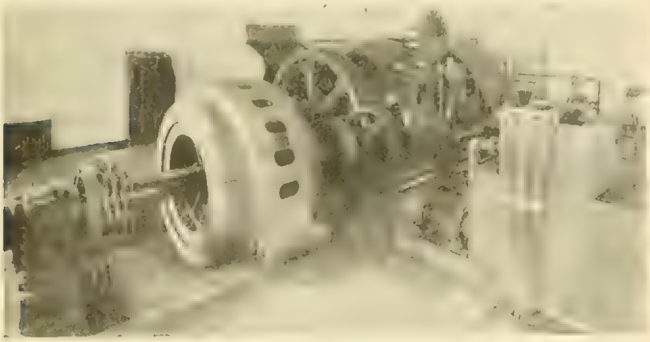


FIG. 10—VIEW OF HOISTING ROOM

Showing operating pulpit and liquid controller. The primary panel is located to the right.

The following disadvantages exist:—

Cooling water is sometimes hard to obtain and if this water has certain impurities in it, the cooling coils deteriorate quite rapidly. If the water is muddy, it is necessary to blow out the coils from time to time. The problems involved in cooling coils in a controller of this kind are similar to the problems encountered in tubular boilers and condensers.

FIG. 11—HOIST OPERATED BY SLIP-RING MOTOR

Showing the 2200 volt hoisting panel, together with the feeder panel in the background.

The controller is harder to operate from a mechanical standpoint than the contactor type, as the mechanical effort required to move the weir up and down is greater than that required for moving the master switch handle.

The controller must be located conveniently to the operating pulpit so that mechanical connections can be made between the lever in the pulpit and the controller.

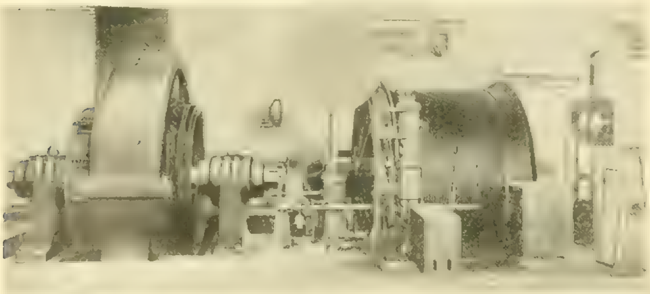


FIG. 12—HOIST OPERATED BY VOLTAGE CONTROL METHOD

The controller consists of a large field rheostat located on the right hand side of the hoisting drum. The large dial in the foreground is a depth indicator.

The contactor control is usually cheaper for motors up to 500 horse-power. The liquid controller is often cheaper for the larger motors. This point of difference is not definite, as it changes with variations in design, and is given merely for general information. Other designs of liquid controllers have been used for smaller motors, but the commercial demand so far has not developed the smaller type of liquid controller to any considerable extent.

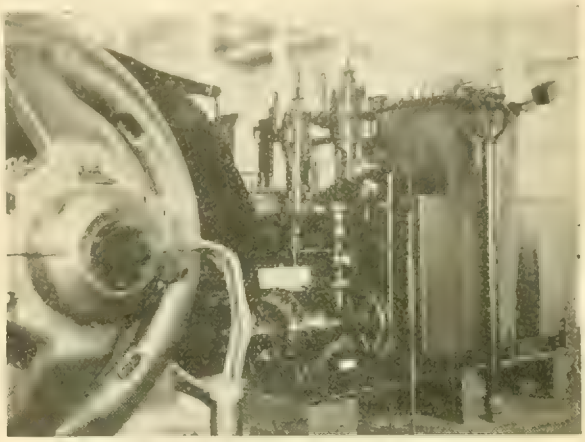


FIG. 13 LIQUID CONTROLLER INSTALLATION

VOLTAGE CONTROL

This control is particularly well adapted to large hoists for deep mines.* It is illustrated diagramatically in Fig. 9. Figs. 10, 11 and 12 illustrate installations of this type. The alternating-current power is supplied to an induction motor which drives a flywheel and a direct-current generator. The direct-current generator is connected to a direct-current hoisting motor. The speed and direction of rotation of the hoist motor is controlled by changing the field strength of the generator. The flywheel serves to store energy during the low demand periods and to give out energy when the demand exceeds the average requirements. This is effected by changing the resistance in the secondary of the alternating-current motor, as described in the article referred to above. Hoists using this system of control have the following advantages:—

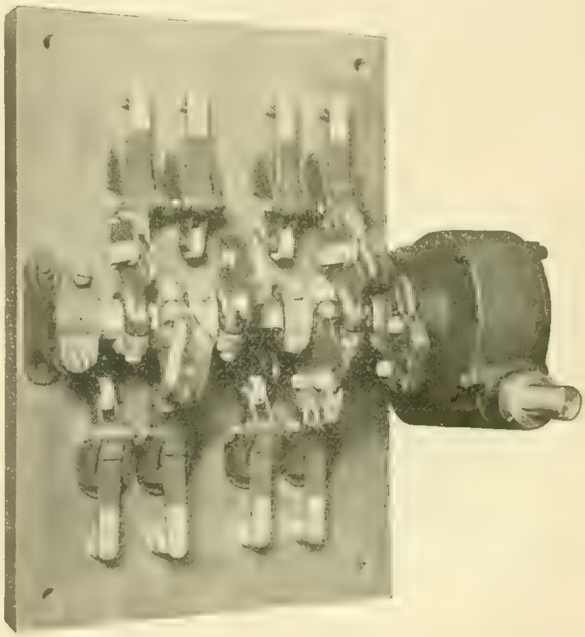


FIG. 14—CAM LIMIT SWITCH WITH WORM REDUCTION GEARING

*The principles of this system of control were described in the JOURNAL, for July 1917, beginning on p. 278.

1—The maximum demand for power can be kept close to the average. Where power is purchased on the basis of a maximum demand, considerable saving in the power bill may be effected by the use of a flywheel motor-generator set.

2—The speed of the hoist motor may be controlled closely under all conditions of load. If the hoist is used for lowering men into the mine, the speed of the cage can be held at the proper value and the hoist operated at a high efficiency, as there are no rheostatic losses except in the field control for the generator which is very small. Where the mine is deep, the lowering of the cage on a mechanical brake presents considerable difficulties and it is preferable to use a system having dynamic braking with speed adjustment.

3—Sufficient energy is stored in the flywheel so that one or more trips can be made with the hoist after failure of power. This may be a distinct advantage in case of interruption of the power supply.

4 Where the hoist is in constant operation, the losses of the motor-generator set are less than the rheostatic losses when the motor is operated directly from the supply lines, so that this system gives an economy in power consumption.

The loss in electric power in the hoisting system represent only a part of the total losses. Assuming that an ordinary hoist has an efficiency of 50 percent and that half of these losses are due to mechanical friction and half due to the electrical machinery and control, we have a possible saving of only 25 percent of the total power if we operate without electrical losses. If the voltage system of control for any particular installation should show half the loss obtained with a rheostatic control, then the total saving in power would be only 12.5 percent. Usually the distribution of losses is such that the saving is less than this amount. The voltage method of control, comprising a motor-generator set, direct-current hoist motor, flywheel, and slip regulator, will often cost from three to four times as much as the ordinary wound rotor motor with rheostatic control. This difference in first cost must be capitalized against the saving in power. Many installations do not use the voltage method of control on account of its higher first cost. On the other hand, where the operating requirements do not lend themselves readily to rheostatic control, a decision favoring the use of a voltage system of control may be made.

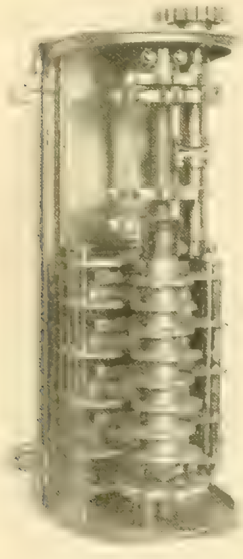


FIG. 15—GEARED LIMIT CAM-TYPE SWITCH WITH TRAVELLING NUT

Since the motor-generator set operates continuously, it is not economical to use this system of control where the hoist motor operates infrequently or has considerable periods of rest. If we assume that the periods of rest are approximately the same for a deep or shallow mine, it can be readily seen that the ratio of operating time to total time for the hoist motor will vary with the depth of the mine and, the deeper the mine, the more economical it will be to use the voltage method of control.

The mining laws in some localities are much stricter than others and have an influence upon the selection of the proper control for the hoist. Each installation must be carefully studied and the type of control arrived at after reviewing all of the features involved. No general rule can be laid down for the selection of a type of control for large hoists.

SAFETY DEVICES

Mine hoists, in common with elevators and skip hoists, have definite limits of travel for the car or cage. It is therefore necessary to provide automatic means for stopping the hoist motor as the cage approaches either limit of travel. Where the speed of the hoist is considerable, it is necessary to slow the motor down before the final stop. This slowing down may be accomplished by gearing limit switches to the drum shaft of the hoist or by a centrifugal device which stops the hoist if the operator exceeds a certain speed as he approaches either limit of travel. For high speed hoists, the latter method seems to be preferable. This centrifugal device consists of governor balls revolved at a high speed by means of mechanical drive from the hoisting machinery. These balls are mechanically connected to a latch which is raised or lowered, depending upon the speed of the hoist. Passing underneath this latch is a cam driven from the hoist. The height of this cam is changed at either limit of travel and so adjusted that the cam will come into mechanical contact with the latch if the speed exceeds a fixed amount at any part of the travel. If the cam engages the latch, a contact is opened which disconnects the hoist motor from the line and applies the brakes. This will usually stop the hoist short of the landing and it will be necessary for the operator to reset the device by hand before he can proceed.

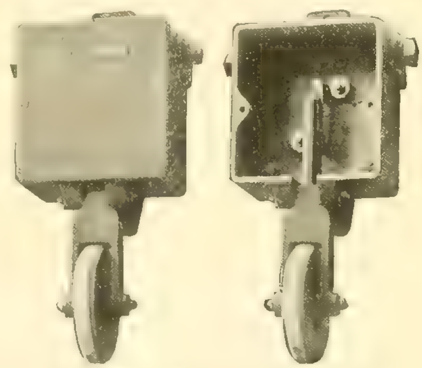


FIG. 16—HATCHWAY LIMIT SWITCH
With and without cover.

A geared limit switch consisting of a series of cams is shown in Fig. 14. The cam shaft is driven from the hoist mechanism. These cams can be set to open their corresponding switches for various positions of the cage. This limit switch usually has several cams, the first providing a slower motion for the hoist and the last one disconnecting the motor from the line and applying the brake. If a centrifugal stop is used in conjunction with the geared limit switch, the geared switch may be used only for the final stop.

A track limit switch which is placed in the runway for the cage and arranged to be tripped when the cage reaches this part of the travel is shown in Fig. 16. Two

of these switches are used, one in the runway for each cage, and they are placed so that they will not operate if the geared limit switch performs its functions properly and constitutes an extra safety stop. When only one cage is used, a single limit stop at the top travel of the cage is usually sufficient.

BRAKES

Small hoists may be provided with a friction brake released by a magnet and applied by a spring or weight. This brake is applied on failure of voltage or when the controller is in the central or off position. It may be applied also by any of the limit stops. For larger hoists, a more elaborate system of braking is necessary. One of these systems uses oil under pressure for operating the brakes. The oil is controlled ordinarily by a lever in the operating stand. In addition, a magnetic valve is so arranged that when the magnet is de-energized, the brake is applied. This magnet can be disconnected from the line by the centrifugal stop, the geared limit switches, the track limit switch, or any other safety means available.

AUTOMATIC CONTROL

The question of controlling hoists so that they automatically stop at either limit of travel and discharge their load, has been considered from time to time, but very few are in use. The control shown in Fig. 4 illustrates one of these hoists. At present direct-current hoist motors should be used. By using the voltage method of control, large motors can be made to slow down and stop automatically. It has been a question, however, whether enough would be gained by this automatic operation to pay for the additional complication. Ordinarily, the stretching of the rope in a deep mine hoist would frequently put such a device out of adjustment. The longer the rope, the greater the difficulty from this source. For shallow mine hoisting, this difficulty is not so serious. The time will probably come when there will be a considerable use made of automatic stopping and discharging of the load from shallow hoists.

ENGINEERING NOTES

Aim—To connect theory and practice

Cementing Porcelain Insulators

No small part of the successful operation of a pin-type porcelain insulator is due to the care with which the several sections are cemented together. Ordinary Portland cement is probably the most widely used and best cement for the purpose.

The cement should be used neat. In mixing, the cement should be worked thoroughly with just as little water as will permit the mixture being worked into the recessed parts with a trowel. In no case should it be allowed to stand more than one-half hour before using, and if any setting has taken place it should not be thinned again with water, but it should be thrown away and a new lot mixed.

In mounting, the parts to be cemented should be assembled in their proper relative positions, and held there by a jig or by blocks or wedges to make sure that all parts fit properly. The parts should then be seperated and wet and then the cement placed in the recess to be cemented. In reassembling, the parts should be worked well into position, so that the cement is forced into all grooves and irregularities of both the recessed and inserted parts.

Care should be taken when cementing together the different porcelain parts that cement does not extend beyond the point of distance indicated on the drawing. When cementing pins in insulators, the cement should not extend beyond the threaded part of the hole for the pin. The assembled unit should then be clamped or wedged firmly in position.

The completely assembled insulator should then stand in moist air for 24 hours, after which the cemented parts should be covered with water for an additional 48 hours, if the shape of the porcelain is such that this can be conveniently done; otherwise the unit should stand in moist air for a total of 72 hours. Good results can be obtained by covering the insulators with a wet cloth, waste or excelsior arranged to extend into a vessel of water in such a way as to insure a constant supply of moisture. A final drying of 24 hours in the open air is then recommended.

Protective Resistors for Instrument Transformer Fuses

The energy that may be dissipated in a short-circuit is not dependent upon the normal current of the circuit, but upon the impedance of the circuit and the k.v.a. capacity of the supply. A short-circuit at the high-tension terminals of an instrument potential transformer is, therefore, likely to be very severe, unless some device for limiting the flow of current is provided. This follows from the usual practice of connecting instrument potential transformers directly to the bus-bars through fair sized conductors, which because of their short length afford but little impedance. Commonly, a light fuse has been used to interrupt the current to the potential transformer in case of excessive demand, but this arrangement is not adequate when the amount of energy that may be delivered through the fuse exceeds 10000 k.v.a., for this is roughly the maximum interrupting ability of the usual enclosed cartridge type of fuse.

Protective resistors have been proposed and are now coming into common use as a means of limiting the current passing through the instrument potential transformer fuses, so that, in cases of short-circuit, the fuses will be able to open the circuit. Such resistors continuously carry but the very small current normally flowing in the high-tension windings of the instrument transformers, commonly but a few hundredths of an ampere, and limit the maximum currents in times of short-circuit to between 20 and 40 amperes, which can readily be interrupted by the usual fuse. At the same time no material inaccuracies in metering are introduced by the use of these resistors.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A personal reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1590—Slip Regulator—The voltage impressed on the stator of an induction motor with a slip regulator, Fig. (a), is 550, and the open circuit voltage induced in the rotor is 750. Considerable trouble has occurred on account of the rotor winding breaking down to ground at the neutral connection, marked X. The slip regulator frame and coils for cooling are metallically grounded through the water system. It is my opinion that

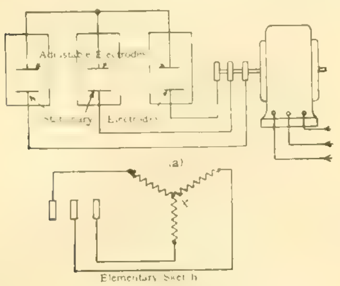


FIG. 1590 (a)

this regulator should be insulated from ground to minimize the tendency of the windings of the rotor to break down. The objection, of course, to this remedy would be that some safeguard would be needed to prevent the human element from coming into contact with it.

R.H.N.L. (BR. COL.)

Slip regulators are built with grounded tanks on the theory that the resistance in each phase is equal. This being true there would be zero potential between the regulator tank and the ground connection on the motor and therefore no current will flow through this ground connection. When there is a flow of current through the ground connection, adjustments of the electrodes should be made to balance the resistance in each phase. G.W.H.

1591—Power-Factor Readings on Alternator—A three-phase alternator is carrying a balanced non-inductive load. To phase *1-2* an inductive load is added of approximately 60 percent. There is an ammeter in each phase of the circuit and it is found that the ammeters in phases *1* and *2*, do not increase the same amount when the inductive load is added. If to the original balanced non-inductive load, loads of varying power-factor are added, it is found that as the phase of the added load is reduced, the difference in the ammeter readings in the two legs of the phase to which the inductive load is added, becomes greater, and as the power-factor of the added load is increased the ammeter readings in the two legs of the phase to which the load is added become nearer and as the added load approaches unity power-factor the two meter readings in that phase will be the same. Will you please explain this phenomenon and give a vector diagram showing how the results are obtained? R.F.H. (MAN.)

The vector diagrams, Fig. (a), show the effect of combining a single-phase with a balanced three-phase load. The vectors, *OA, OB*, and *OC*, Fig. (a),

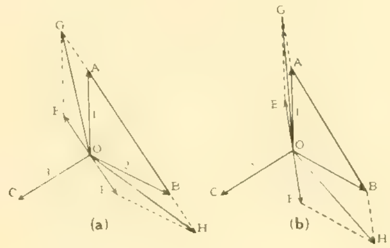


FIG. 1591 (a) and (b)

represent the currents in the three phases due to the balanced load only. These vectors may be used to represent the three voltages also, and a line drawn from *A* to *B* will then represent the terminal voltage across phases *1* and *2*. If a single-phase load is applied to these terminals the current may be shown by two vectors drawn so as to be directly opposite to each other and making angles with the voltage vector, *AB*, which are determined by the power-factor of the load. The reason for using two vectors is apparent when it is considered that the position of the vector, as ordinarily employed for three-phase circuits, represents the time at which the current in a certain phase is a maximum and in a direction outward from the star. Since the single-phase current flows toward the star in phase *2* at the same time it flows out from star in phase *1*, it must be represented by one vector for phase *1* and by a vector with opposite direction for phase *2*. The length of each of these vectors, in a diagram drawn to scale, is such as to represent the total current due to the single-phase load. Referring to Fig. (a), the vector *OE* represents the additional current in phase *1* due to unity power-factor, single-phase load on phases *1* and *2*. Under this same condition the additional current in phase *2* is represented by the vector *OF*. The combination of *OA* and *OE*, which is *OG*, gives the resultant current in phase *1* and similarly the combination of *OB* and *OF*, which is *OH*, is the resultant current in phase *2*. In this case the resultant currents in the two phases are equal. Fig. (b) shows the effect of a single-load of less than unity-power power-factor. Under this condition the resultant currents, *OG* and *OH*, are not equal. O.G.

1592—Capacity Effect of Cables—Please give me some data on the capacity effect of cables, or a formula to calculate this for standard cables.

R. F. C. (PENNA.)

The capacitance of three-phase cables can be calculated by means of the following formula,—

$$C_2 = \frac{0.179\,K}{6\,\log_e \dfrac{R^6-d^6}{3\,R^2\,d^2\,r}} - \frac{0.179\,K}{6\,\log_e \left\{\dfrac{d\sqrt{3}}{r} \times \dfrac{R^2-d^2}{(R^4+R^2\,d^2+d^4)^{1/2}}\right.}$$

$$C_1 = \frac{0.179\,K}{6\,\log_e \dfrac{R^6-d^6}{3\,R^2\,d^2\,r}} + \frac{0.179\,K}{3\,\log_e \left\{\dfrac{d\sqrt{3}}{r} + \dfrac{R^2-d^2}{(R^4+R^2\,d^2+d^4)^{1/2}}\right.}$$

Where C_2 *and* C_1 are microfarads per mile; K specific inductive capacity of the dielectric; r, d and R are given in Fig. (a).

FIG. 1592(a)

The capacitance for various combinations of circuit are as follows:—

Effective capacitance per lead for normal three-phase operation,— $C_0 = C_1 - C_2$;

Capacitance between *1* and *2* (*3* grounded) $= \frac{1}{2}(C_1 - C_2)$;

Capacitance between *1* and *2, 3* $= \frac{2}{3}(C_1 - C_2)$;

Capacitance between *1* and *s* (*2* and *3* insulated) $= \dfrac{(C_1 - C_2)(C_1 + 2C_2)}{C_1 + C_2}$

Capacitance between *1* and *s, 2*, (*3* insulated) $= \dfrac{(C_1 - C_2)(C_1 + C_2)}{C_1}$

Capacitance between *1* and *s, 2, 3* $= C_1$;

Capacitance between *s* and *1, 2* (*3* insulated) $= \dfrac{2(C_1 - C_2)(C_1 + 2C_2)}{C_1}$

Capacitance between *1, s* and *2, 3* $= 2(C_1 + C_2)$;

Capacitance between *s*, and *1, 2, 3* $= 3(C_1 + 2C_2)$.

s represents the lead sheath.

The above formulae are from "Formulae and Tables for the Calculation of Alternating Current Problems" by Cohen. J.F.P.

1593—Direct-Current Motor Trouble —I am having some trouble with a five horse-power, 220 volt, four-pole, direct-current shunt motor. The commutator has 69 bars, armature 35 slots, the form-wound coils are taped two coils together, and on testing the coils I did not find any short-circuits between adjacent coils, although there is considerable flashing at the brushes. I have concluded that some individual coils must be short-circuited. There are about seven or eight turns in a coil, but I have no means of testing an individual coil for short-circuits. Could you give me such information? The coils are all disconnected from the commutator and some of them removed from the armature. The machine is wave wound, and I am connecting coil one to segments *1* and 35 (pitch 34). Is this correct? In what segments should this coil connect with regard to the slot the coils lies in (ex: the front and back leads the spacing on commutator ahead and back of the slot). The motor is sometimes subjected to excessive voltage on account of poor operation of the governors on the engine driving the generator supplying power for the motors. This is caused by other motors being shut off. We have had experts at work on the governor but its action is still poor. Can I get any advice that will protect this motor from getting too high voltage. J. B. (ONT.)

The relatively small number of commutator bars and large number of turns per coil is probably the principal cause of trouble in this machine. This is a bad combination since it gives a rather large voltage between commutator bars which is apt to cause sparking or even flashing, especially when the line voltage is varying and is sometimes excessive. The commutation may be improved by undercutting the commutator mica. Also if the motor has commutating poles, a check should be made to see if the brushes are on neutral. This may be done by running the machine, at full load if possible, in both directions with the same shunt

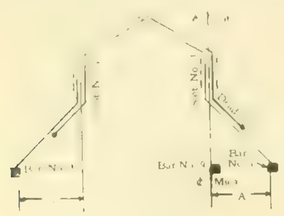


FIG. 1593(a)

field current. If the speed is the same for both directions of rotation, the brushes have the proper position. If the brushes do not have the proper position they should be shifted around the commutator until that setting is found which will give the same speed for both directions of rotation for the same load and field current. In addition, the brush spacing should be checked, that is, the brushes should be equally spaced, measuring around the commutator. With the instruments that are ordinarily available there is no accurate method of checking the individual coils for short-circuits. By reading the voltage drop through each coil for a given current, a short-ciruited coil, that is, one whose drop is lower than the rest, may be detected. The method of connecting the coils is shown in Fig. (a) for a set of coils which are made to span nine slots. There will be one dead coil and the winding should be started with the pair which includes the dead coil as shown. If the coils are not formed to fall in slots 1 and 10, the distance *A* will be different from that shown but should be made such that *A* and *B* will be approximately equal. There is no method of protecting the motor from excessive voltage without interrupting the operation during the period of excessive voltage. R.W.O.

1594—Transposition of Conductors—I have two banks of transformers, each bank consisting of three, 2500 k.v.a., single-phase, 44 000 to 2200 volts, 60 cycles transformers connected delta-delta. The two banks operate in parallel with 75 percent full load; the cables on the secondary side of the transformers connecting the bus marked "X", become excessively hot. The size of each cable is 750 000 circ. mils *i. e.* total capacity for each lead connecting bus is 2 250 000 circ. mils which should be of ample capacity without any undue heating. As can be seen by Fig. (a), each cable has a separate four inch fiber duct with centers six inches apart and each phase 18 inches apart. It is my opinion that increasing the size of the cables will not eliminate this trouble. I attribute the trouble to induction and that the only safe method to overcome this would be some form of transposition. Such a scheme I illustrate in Fig. (b). Please let me know if arranging cables as shown in Fig. (b) is the most practical method of overcoming this difficulty. If not, illustrate how the trouble can be overcome. R.H.N.L. (BR.COL.)

The arrangement of the cables shown in Fig. (b) should give a better current distribution among the parallel conductors than the cable arrangement

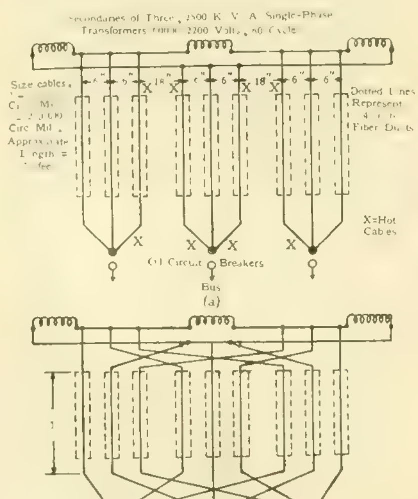


FIG. 1594(a) and (b)

shown in Fig. (a), and the excessive heating of individual cables should be considerably reduced. The degree to which the current can be made to distribute equally among the parallel conductors depends on the extent that the transposition and interlacing of the conductors makes the circuit symmetrical. In general the most practicable method of equalizing the current among parallel conductors of a polyphase transmission system is by transposing and interlacing the conductors of the different phases. In order to illustrate the method of calculating the inductance of any conductor when the cables are arranged as shown in Fig. (b), it is assumed:—(a) that the magnetic effect due to the end connections of the cables can be neglected; (b) that the system carries a balanced load; (c) that the currents flowing in the parallel conductors of each phase are of equal value and in phase; and, (d) that the current distributes uniformly in each conductor. If the currents in the different phases are displaced 120 degrees and *I* is the maximum value in each conductor, the inductance of any conductor, as a_1, can be calculated from the following relation: The self-inductance of conductor a_1 —of radius *r*, is

$$L_{a1} = 2l\left[\log_e \frac{2l}{r} - 0.75\right] \textit{centimeters} \quad (1)$$

The mutual inductance of any other conductor on a_1 is

$$M_{a1x} = 2l\left[\log_e \frac{2l}{r} - 1 + \frac{D}{e}\right] \textit{centimeters} \ldots\ldots (2)$$

where *D* is the distance between the respective conductors and a_1 and *l* is the conductor length, as shown in Fig. (b). The total flux interlinking a_1, at any instant of time, *t*, is

$$F = 10^{-1} I\Big[s \sin \omega t + R \sin (\omega T + 120) + \sin (\omega t + 240)\Big] \ldots\ldots (3)$$

Where $S = L_{a1} + M_{a1a2} + M_{a1a3}$;
$R = M_{a1b1} + M_{1b2} + M_{a1b3}$;
$T = M_{a1c1} + M_{a1c2} + M_{a1c3}$

All dimensions in Fig. (b) and in the equations are in centimeters.

The instantaneous voltage induced in conductor a_1 due to the pulsating flux, *F*, is

$$C = 10^{-9} \frac{dF}{dt} \ldots\ldots (4)$$

which has an effective value

$$E = 10^{-9} \frac{I}{\sqrt{2}} \frac{\omega}{2} \left\{(2S - R - T)^2 + 3(R - T)^2\right\}^{\frac{1}{2}} \ldots\ldots (5)$$

Therefore, the inductance of conductor a_1 is

$$L = 10^{-9} \times \frac{1}{2} \left\{(2S - R - T)^2 + 3(R - T)^2\right\}^{\frac{1}{2}} \textit{henrys} \ldots\ldots (6)$$

In calculating the inductance of a conductor under actual conditions in which the current does not distribute equally among the parallel conductors it is necessary to determine the actual value and phase relation of the current flowing in each conductor. This can be accomplished by a cut and try method of approximation or by the solution of a system of simultaneous equations involving the unknown currents, either of which is too extended for the Question Box. C.M.L.

1595—Measuring Power From Improperly Connected Transformers—A power customer having a load of 600 kw at 80 percent power-factor was originally supplied by two 300 k.v.a. transformers connected in open delta. These transformers had each an impedance of 2.43 percent and a resistance of 0.57 percent. A third transformer was later added to the bank so as to close the delta connection. This transformer was of 300 k.v.a. capacity but had an impedance

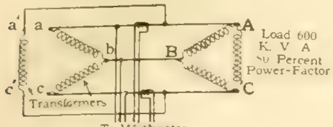


FIG. 1595(a)

of 4.05 percent and a resistance of 1.05 percent. In connecting in the third transformer an error was made in bringing the secondary leads to the load side of the current transformers which supplied the watthour meter, as shown in Fig. (a), causing an incorrect amount of energy to be recorded. It is my object to determine what the true power output of this transformer bank was.

H.M.J. (MASS.)

This question would be difficult to answer unless it can be assumed that the load is balanced on the three phases. On the assumption of a balanced load, suppose first that the instrument transformers had been connected with the line between the transformer and the load, so as to measure the current in the line. In this case the wattmeter would have recorded,—

$$P = I_{aA} E_{ba} \cos \theta_1 + I_{cC} E_{bc} \cos \theta_2$$

Now assume $I_{aA} = I$

then $I_{bB} = I(-0.5 - j0.866)$

and $I_{cC} = I(-0.5 + j0.866)$

Also if the power-factor of the load is 80 percent, the voltages from neutral to the three lines are respectively:—

$$E_{oa} = E(0.80 + j0.60)$$
$$E_{ob} = E(0.1196 - j0.9928)$$
$$E_{oc} = E(-0.9196 + j0.3928)$$

The power measured by the first wattmeter element is,—

$$P_1 = I_{aA} E_{ba} \cos \theta_1 = I_{aA}(E_{oa} - E_{ob}) \cos \theta_1$$
$$= I_{aA} E (0.6804 + j\,1.5928) \cos \theta_1$$

But since, in this case, I_{aA} coincides with the reference axis the real component of E_{ba} is the same thing as $E_{ba} \cos \theta_1$,—

$$P_1 = I E \times 0.6804$$

Where I is the current in the line and E is the voltage from neutral to line. The power measured by the second wattmeter element is obtained by rotating both current and voltage vectors until the current vector coincides with the axis of reference, after which the procedure is the same as above.

$P_2 = I_{cC} E_{bc} \cos \theta_2 = I(-0.5 + j0.866)(E_{oc} - E_{ob}) \cos \theta_2 = I(-0.5 + j0.866) E (-1.0392 + j\,1.3856) \cos. \theta_2$

To rotate these vectors to the desired position each one must be divided by $(-0.5 + j0.866)$ [or multiplied by $(-0.5 - j0.866)$]. This gives $P_2 = I E (1.7196 + j0.2072) \cos \theta_2$, or $P_2 = I E \times 1.7196$. $P = P_1 + P_2 = 2.4\, E.I.$

This result is the same as taking three circuits with current I, voltage E and power-factor 80 percent.

$$P = 3 \times 0.8 \times E\, I = 2.4\, E\, I.$$

Now let the third transformer be connected between the series transformers and the load, as in the actual case. By the method described in the article on "Dissimilar Transformers in Delta" in the Journal for Sept. 1917, p. 356, it is found that the currents in the three transformers are respectively,

$$i_{ab} = I(-0.588 - j0.23)$$
$$i_{bc} = I(-0.088 + j0.633)$$
$$i_{ca} = I(+0.712 - j0.232)$$

In this case the power measured by the wattmeter is

$$P = i_{ba} E_{ba} \cos \theta' + i_{bc} E_{bc} \cos \theta''$$

Since i_{ab} is $\sqrt{(0.588^2 + 0.23^2)}\ I$, or $0.63\ I$ in magnitude, to rotate i_{ba} and E_{ba} into the desired position they must be multiplied by $\frac{0.63}{0.588 + j0.23}$. This gives

$$P_1 = I(0.588 + j0.23) \times \frac{0.63}{0.588 + j0.23} E$$
$$(0.6804 + j\,1.5928) \times \frac{0.63}{0.588 - j0.23} \cos \theta'$$
$$= 0.63\, I E (0.767 + j\,0.781) \times \frac{0.63}{0.4} \cos \theta'$$
$$= 0.767\, I\, E.$$

Similarly $P_2 = i_{bc} E_{bc} \cos \theta'' = i_{bc}(E_{oc} - E_{ob}) \cos \theta'' = 0.63\, I E (0.9684 + j\,0.535) \times \frac{0.63}{0.4} \cos \theta'' = 0.968\, I\, E$ and $P = P_1 + P_2 = 0.767\, I\, E + 0.968\, I\, E = 1.735\, I\, E.$

That is, the power actually measured was $\frac{1.735}{2.4} = 72.3$ percent of the power delivered.

J.B.G.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

MAY 1918

Precautions to be Taken with Blower Installations on Motor Cars

In mounting blower equipment, a number of considerations should be kept in mind. The part of the equipment which causes the most confusion is the blower and motor unit itself as a number of interferences may be caused by the brake rigging and construction of the underframing of the car body.

EFFECT OF CAR STRUCTURE ON BLOWER MOUNTING

With some types of cars where a box girder is used for the center sills it is possible to build the car underframing so that the box girder itself can be used for the main air duct. With this construction, the blower casing can be mounted underneath the car with the intake arranged to take its air

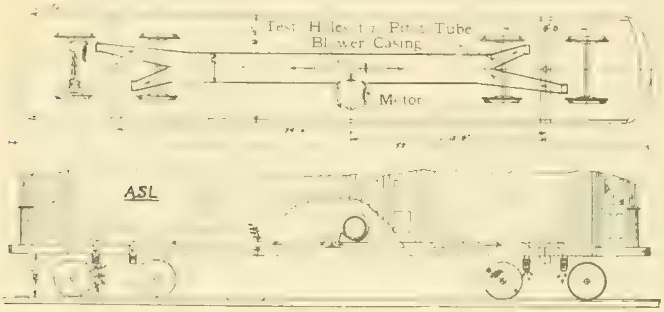


FIG. 1—TYPICAL BLOWER LAYOUT ON MOTOR CAR

from an air box, with louvers placed underneath and at the side of the car. The air box in this case should be equipped with baffles to prevent dirt from entering the blower, as most of the dirt which is taken into the blower eventually gets into the motors.

Where the center box girder is used, the question of flexible connections to the motors from the main duct may be troublesome. In many cases the distance from the top of the main motor in the truck to the car underframing is so small that it is impossible to make a satisfactory connection between the auxiliary air duct and the opening in the motor housing. The capacity of the auxiliary air duct must also be sacrificed.

While these conditions are not satisfactory from the standpoint of flexible connections, they are somewhat better than the arrangement necessary with a car underframing having the center sills on the same level as the side sills, where I-beams are used for the center sills, due to the small amount of room for the main air duct.

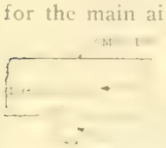


FIG. 2—CORRECT METHOD OF TAPPING MAIN DUCT

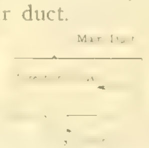


FIG. 3—WRONG CONSTRUCTION OF MAIN DUCT TAPPING

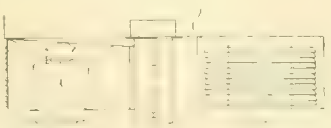


FIG. 4—CONSTRUCTION OF BLOWER INTAKE DUCT AND LOUVERS

The ideal condition of blower mounting and duct arrangement, where other features such as space factor, etc., do not interfere, is to have the blower and operating motor mounted inside of the car directly over the main air duct which is laid between the main floor and a false flooring. This layout is shown in Fig. 1. This case is probably an exception because the car in question is used as a locomotive where the inside mounting of the blower does not interfere with the operation, as would be the case in a passenger car.

BALANCING AIR VOLUME

The test holes shown in Fig. 1 for measuring the air pressure, while not essential, are of considerable help in balancing the air delivered to each motor. In making use of the test holes the amount of air can be varied by means of baffles placed in the main ducts. Care should be taken when using baffles to see that all bends are made on a radius, as sharp corners tend to reduce the velocity pressure and indirectly the amount of air delivered.

SIZE OF DUCTS

The cross-section of the main ducts should be such that the pressure loss is not increased beyond safe limits established by the required pressure at the motor. This can be understood from the following example:—With a layout to deliver 800 ft. of air per minute to each of four motors with two motors on a truck, the main duct which has a cross-section of approximately one square foot running to each truck will be required to carry 1600 feet per minute with a given pressure and

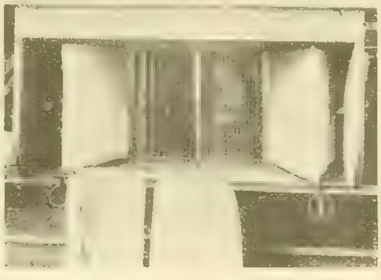


FIG. 5—METHOD OF SCREENING THE BLOWER INTAKE

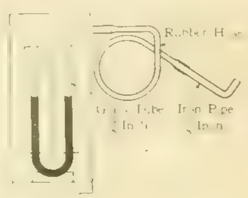


FIG. 6—ARRANGEMENT FOR MEASURING THE PRESSURE OF THE AIR TO BLOWER MOTORS

a certain loss. Reducing the area to one-half square foot, the air will have to travel at twice the speed to deliver the same amount of air. The resistance of the duct will be approximately twice as great, requiring an increase in pressure to force the same amount of air through the duct. As the speed, and hence the pressure, of a railway blower unit is usually fixed, there will be a reduction in the total amount of air delivered to the motors. It is usually a good plan to keep the area of the duct the same as the openings in the blower, or slightly larger where space permits. When arranging the duct opening for connecting the canvas bellows, care should be taken to have the opening of the duct directly over the motor opening, with the truck in the normal position, so as to give as little restriction to the passage of air as possible. In cases where the distance between the opening in the duct and the motor is short, a canvas tube may give better results than the specially constructed bellows.

Ducts can be made of any easily worked material, including wood, provided all joints are made air tight.

AIR TAPS

When it becomes necessary to make a number of consecutive taps in the main duct, it will be necessary to either reduce the size of the main duct after each tap or provide suitable baffles to deflect the air. If this precaution is not taken with a system using relatively high velocity pressures, the taps at end of main duct will take more than their share of the air. When making a tap from the main duct, construct as shown in Fig. 2 and not as in Fig. 3.

To decrease the noise caused by the intake of the blower, the duct leading to the intake should be made large and tapering as shown in Fig. 4. If the roadbed is very dirty, screens made of cloth known as "scarfing" can be used. A screen which has been successfully employed is shown in Fig. 5. A simple instrument for measuring the air pressure for balancing the amount of air to each motor is shown in Fig. 6.

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The Future Power Station

The unparalleled increase in the demand for electric power service brought about by the war, especially in those parts of the country where manufacturing operations predominate, furnishes a strong indication of the probable developments in the future of the central power station. A large proportion of the manufacturers who have come to use electric service in an emergency will doubtless remain with the central station interests as a permanent load. Their demands may be modified but the advantages and flexibility of central station service will be impressed upon them.

The desirability of interconnection between central power houses to take advantage to the fullest extent of diversity factor in time and load has also been clearly shown. In certain sections of the country plans are already under way looking to a working interconnection of large distributing systems, enabling great volumes of power to be distributed over large areas with a maximum economy and reliability.

In England it has been proposed by the Government to erect a limited number of super-power houses at suitable locations, interconnected with a system of transmission lines covering the entire country; the high economy of the modern power house and turbine render such a system economical in cost and in operation and therefore desirable. Within the next few years we will probably see such centralization of power generation with widespread interconnected distributing systems.

The requirements of water for condensation for large central stations definitely allocate such power houses along our rivers and inland lakes, a fact which in itself dictates the economy of comparatively few generating stations of very large size. Attendant with this development will come an increased conservation of fuel through boilers and stokers of higher efficiency, possibly the use of powdered fuel and certainly eventually the gassification of the fuel, with the saving of the enormous values of tar, ammonia and toluol that are now being wasted.

As a prime mover the turbine will probably hold the field for some years but the greater demands of the public for power, together with the need for economy in both fuel and labor, may possibly result in the production of units much larger than any which have now been constructed. Some fifteen years ago it was believed that the limit had been reached with turbines of 5000 kilowatts capacity. Development, however, did not stop and today units have been built and are being successfully operated of 30 000, 35 000 and 40 000 kilowatts capacity, with incomparably higher economy both as regards fuel consumption and attendant labor. The 5000 kilowatt unit of fifteen years ago would be an impossible size in the modern power house. Units of 30 000 to 40 000 kilowatts capacity are suitable and possibly are large enough for the type of super-power houses which can be foreseen in the future. While we do not believe that units of this size have been brought to their ultimate state of perfection, personal experience with five months' operation of a unit of the maximum size has convinced the writer of its reliability and general trustworthiness for central station power production.

A more serious matter than the question of a relatively small variation in the capacity of the turbine unit adopted or in a variation of the nominal turbine economy of a few hundredths of a pound, lies in the production of steam for power requirements. Relatively little attention has been given heretofore to the handling of the coal or fuel from its receipt to the boiler room and of the refuse to the ash pile. Boilers have been piped up and put in service in every conceivable way and under every conceivable condition, and variations in full pounds in steam economy exist between central stations which are actually using the same size and type of turbine under substantially the same operating conditions, which variation is due directly to the means of steam generation and distribution employed.

Economy in the super-power station is to be arrived at more by careful consideration of the boiler house, the completeness of combustion in the fuel, the prevention of heat radiation, stack losses and leakage losses, than in any other manner. No other power house subject presents so great an opportunity to operating or consulting engineers for the improvement of economy in operation and increase of operating returns.

C. S. Cook

War Time Problems of the Utilities

The public utilities, in the main, welcomed the advent of State regulation. While it was accompanied by the introduction of certain rules and restrictions with regard to the application of rates, conditions and measurement of service, accounting practice, issuance of securities and other matters, the same regulation in most cases provided protection to the utility against ruinous competition. During the beginning of this new era, the utilities did not always fare so well at the hands of the Commission exercising jurisdiction. In some instances, the members of the new tribunals were unfamiliar with

the underlying factors of the public utility business which they had been called upon to regulate. Consequently they proceeded cautiously and in their ultra-conservative action wrought real injury to the property and consequently its owners, all of which was later on reflected in the quality of the service rendered. Improvement in the situation, however, has been in evidence during the past year or two and, where the Commissions have had the benefit of an experienced staff or have had individually the opportunity to acquire at first hand a clear conception of the nature of the service and the features surrounding its development, they have meted out a greater measure of justice to the utilities.

Previous to the war, adjustment of rate questions presented a very different problem from that which confronts us today. Organizations could readily be recruited to investigate the conditions and costs; wages and material prices were normal, and no particular harmful effect resulted if some time was consumed in conducting inquiries. More recently matters have taken a new turn. While prices began to rise soon after the outbreak of the European war, the utilities, by the application of strict economy and the installation of more efficient equipment, combatted the situation for a time, not, however, without many difficulties. With their stores of low-priced materials being depleted and coal—their chief item of consumption—having soared excessively in price, their ability to offset the rising tendency in operating costs had been exceeded. Moreover some of the most competent employees of the utility companies entered the service of the government, leaving them without satisfactory substitutes to continue the different lines of investigation into efficient practices and methods.

Increased costs became so alarming during the middle of 1917 that rates were raised quite generally. But, owing to the technical procedure involved, some companies encountered difficulty in getting the increase into effect. Protest against proposed increases places the burden of proof of reasonableness upon the utility company. Heretofore, a valuation was viewed as the only definite test of the propriety of a system of rates. Few utility companies had records that would reveal the true valuation of their property and accordingly, if the test was to be applied in conformity with the law, as so frequently interpreted, an extensive appraisal could not be escaped. It is well recognized at present that men should not be diverted from essential war work to engage in investigations of this kind. Our war industries are already seriously undermanned. An alternative must be determined upon and the recent policy, laid down by the New Hampshire Public Service Commission, in effect to proportion requirements upon the basis of conditions and costs existing in the immediate pre-war period, blazes the trail. This solution is the most logical one so far propounded and affords a simple but convincing basis upon which to proceed.

It is and should be incumbent upon the utility to present its case in a thorough manner, giving fully the elements and conditions which have contributed to the disproportionate increase in operating expenses as compared with any changes that may have taken place with respect to earnings. With the facts clearly set forth, the force of opposing argument should be practically dissipated at the outset and thereby the commissions should no longer have cause to demur in sanctioning the necessary increases.

Another dilemma has made its appearance as a corollary of the extraordinary war time situation. The government has virtually commandeered the investment market and the public utilities, as a consequence, are without new money to provide the increased facilities demanded by their consumers, many of whom have engaged in the manufacture of war supplies. Even if the money was obtainable, the high interest rates and the high cost of materials would place the public utilities at a most serious disadvantage, as any recession in activity later on would leave them with a large surplus reserve capacity which had been financed for the temporary need. Few companies could financially endure such a condition since the utilities have, by economic laws and more recent regulatory supervision, been obliged to work with a comparatively narrow margin of profit. Additional power facilities must be made available promptly if the war program is to be speeded up. The central station is the only medium through which this additional power should be provided. But with the permanency of the requirements of such uncertain nature, the providing of extensions and improvements under present circumstances, in line with previous conditions under which money was supplied, would involve unsound financing. Hence some measure must be inaugurated for rendering financial aid to the utilities either as a direct subsidy or else in the acceptance and carrying, on the part of the government, of long-time funded obligations of the utilities under favorable interest rates.

If the plan were approved by the regulatory bodies, and it were feasible from a business standpoint, new financing would be simplified by arranging that the new extensions be paid for out of earnings within the period during which it is estimated that the extra demand will prevail, say one to three years' time. This conforms to the practice of the manufacturer, who adjusts his prices for war materials, so as to defray the cost of additional buildings and facilities required to enable the order to be filled. Unfortunately the hard and fast principles. which have been slowly developed under regulation, practically preclude such consideration and the question resolves itself into a proposition of government assistance, providing long term financing and subsidy to the extent of the super-costs entailed.

The public utilities are now the essential nerve fibres of industry and it is therefore of national importance that they be aided at this time. Since their facilities are so closely interwoven with all war industries, aiding the utilities becomes a defense measure. In a degree, like furthering the munitions supply, it is one of the strands of that immense cable by means of which we are striving to keep our democratic form of govern-

ment safely anchored. The public service companies are having enough difficulty in securing their operating supplies and maintaining their organizations without being placed under great financial strain. Relief must come and, when the necessity is fully realized by public authorities in control, the means for providing the new facilities will undoubtedly be supplied. No more forcefull acknowledgement of the present status of the utilities is to be found than in the last annual report of the comptroller of the currency. It would appear that the recently created War Finance Corporation provides the necessary organization through which government support may eventually be forthcoming, and as soon as the legislative branch of the government provides the required legal authorization for the purpose, the present deficiency and unsettled state of affairs will doubtless be removed. EDWIN D. DREYFUS

The Epic of Turbine Development

There are few subjects before our utility companies more important than the question of large generating units; and their operating record will continue to be of increasing interest. In the past two years a large number of these units have been contracted for, most of which are under construction. There have, moreover, been quite a number of them installed of the different types and the history of their economic value is now in the making.

First and foremost will be the question of their reliability, for with the large investment in these single units and with the larger service requirement of the individual machine, it seems almost axiomatic that their continuity of service shall be substantially assured. If we regard the 20 000 kw size as the dividing line between the older practice and the new, calling the sizes above that the larger machines that represent the later practice, we now have an operating record of some three years on these bigger sizes which shows them to be entirely reliable, probably more dependable machines from an operating standpoint than their smaller predecessors. Experience has shown that there is nothing in the question of size *per se* that should interfere with the successful use of machines as large as the conditions may warrant. There are considerations of design introduced by the handling of these large volumes of steam that do require most careful thought, but on which we can keep well within the lines of well established practice.

The question of reliability being settled, the efficiency of these large machines is so much better than that of the largest sizes of three or four years ago that they have become an economic necessity. With fuel expense rising, as it has, to 70 percent of the plant operating cost, we can hardly ignore an improvement in the prime mover steam consumption of ten percent or better, even if there still remain so many other things that we can do with the balance of the plant to improve the station efficiency.

When one reviews our central station history for the past two decades and recalls the new standards that have been set up every three to five years, the plant cost cut in half, the fuel consumption also cut in half, the largest stations increasing meanwhile six-fold in size, he is bound to feel that our engineers in their quiet and unobtrusive way have been the real heroes of an epic tale that would well stand the telling. And the truth and the beauty of it all is that the parts they have played in the romance of these great achievements have seemed to them nothing more than the duty seen and performed, the knowledge gained and applied, the emanations of a day's work. E. H. SNIFFIN

Industrial Heating

Those who have studied the electrical heating situation are unanimous in their conclusion that the central station industrial heating load ultimately will exceed the motor load. In fact, one large company which has made an exhaustive survey of possible power users in their territory, estimates that the available heating load is three times as great as the available motor load.

It has been only a few years since electric generating stations were considered as lighting plants, because the motor load was off peak, and the entire plant's operation centered around the lighting load. Within a short period a complete change has taken place. The motor load is now the main load and the lighting load is the off peak load.

The present development in the motor load is due, not alone to the fact that electric motive power is productive of greater economy, reliability of service, increased production and ease of operation, but also to the fact that a demand for the use of electric motors was created by the persistent and combined efforts of the central stations and electrical manufacturers. Industrial heating is making extraordinarily rapid strides, considering the amount of effort that has been put into it. If we electrical men will devote the same energy to the development of industrial heating as was done in the development of the motor load, we will secure in less time a much greater load; a load which ultimately will be the main consideration in the location and design of power plants, and which, unlike the lighting load or present motor load, will not have enormous peak periods, with plant equipment standing idle from eight to sixteen hours each day.

The industrial heating load will not necessarily come on top of the motor load. At present many power plants are struggling during the day to carry an industrial load, while at night the load is relatively small. In the majority of cases the heating operations in an industrial plant may be carried on entirely independent of all other operations. Consequently, there is the possibility of having this load regulated so as to come on the power plant only at stated times in accordance with a predetermined schedule, filling up all the valleys in the power curve.

Numerous cases have arisen recently where a manufacturer, who was anxious to electrify and had been refused power by the central station on account of the overloaded condition of the power plant during the

day time, was entirely willing to operate at night only. It usually does not occur to the power user that the central station could supply the necessary power during the night, or that he could perform his particular heating operation at night just as well as during the day, and at a much less expense.

In the development of the motor load it was necessary for the central station to have specially trained men who could talk intelligently to the prospective customers about their particular problems and help in their solution. Just as this was true of motor application work, so is it true of industrial heating. In order to develop the industrial heating load a considerable amount of missionary work must be done and the sooner this initial stage is passed, just that much sooner will the central stations begin to reap the benefit of their efforts. But to do missionary work one must have some definite object, and there must be apparatus available for the applications with which the power solicitor will come in contact. Several of the larger electrical heating companies have formed industrial heating departments for the development of industrial heating, and are bending their efforts to the development and manufacture of new and suitable apparatus. New ideas and applications are springing up so rapidly that it is now a matter of selecting only those that offer the widest field. Frequently, those applications that appear special today may be general to-morrow, and the apparatus developed for some specific application perhaps may be used in large quantities in applications altogether different from that originally intended.

The three fundamental properties possessed by the electrical method of heating, making this method of heating far superior to that of any other method, are:—

Application—The electrical heaters, can be applied directly to the object to be heated, at exactly the proper temperature and in sufficient capacity to produce the best results.

Control—By means of suitable control equipment the object to be heated can be maintained at any desired temperature continuously and automatically. The permissible combinations for flexibility and refinement of control are almost unlimited.

Efficiency—The fact that the electric heaters do not require air for the proper production of heat, as is the case with oil or gas, makes it permissible for the heaters to be applied directly to the object to be heated. By means of suitable insulating material properly applied so that practically all of the heat generated will be conducted to the material or object to be heated, a very high thermal efficiency is obtained. This is impossible with gas, oil or coal fuel, since only a very small percentage of the heat is utilized, the larger percentage escaping in the flue gases. This difference in the efficiency of utilization of the heat is the reason why the electrical method can compete with the combustion method on a straight B.t.u. basis, even when the cost for a given quantity of heat is in the order of ten to one in favor of the combustion fuel.

The application of heat to any specific purpose should be made with a definite object in view; such as obtaining a specific result in the working of fabrication of a certain material, or reducing the cost of the heating operation. Accomplishing the first object does not necessarily mean that the second will or should follow, but to accomplish the second necessarily implies that the first also will be attained. To obtain a definite operating result, a study of the heating operation must be made, including not only the material being treated, but the apparatus and processses involved. The object should be not to duplicate the results which are already being obtained by present methods, but to produce a better product.

In many cases, an improved product is secured by means of electric heating at a less cost than is required to produce an inferior article by other methods of heating, on the basis of fuel costs alone. However, the first consideration should be a successful application, with all it implies, regardless of the comparison of the fuel and power bills. If the object is to obtain greater economy of operation by the use of electric power, the investigation extends to the present cost of operation, the cost of electric power when substituted for the existing method of heating, the value of a better product to the manufacturer, an analysis of processes of manufacture for the purpose of placing the heating equipment at the point best suited to fit in with the natural sequence of operations, and to the working out of a system whereby the amount of labor required will be reduced to a minimum.

In many cases, the improvement in the product alone is sufficient to justify the use of electric heat. The rate of heating can be regulated exactly, and the correct operating temperature can be obtained and maintained continuously and automatically throughout the entire heating operation. The difference in the value of a product which is inferior, due to improper heating, as compared to a high grade product, resulting from proper heat treatment, will often make the cost of power entirely negligible.

The use of electric heat permits of experiments being made to determine the best method for applying the heat, the proper rate of heating, and the maximum temperature permissible for obtaining the best possible results. And once these factors have been determined, the desired conditions may be reproduced day after day without variation.

After the war is over many industrial plants throughout the country will probably find themselves over-motored for their requirements. If this falling off does not occur, certainly there will be a period in which no marked increase in loads will be produced by the addition of motors. During this period the central stations will need the industrial heating load. While most central stations are not soliciting new business now, they could with advantage take on considerable off peak industrial heat load. Moreover to take full advantage of the opportunity which electric heat will undoubtedly afford in the future, the commercial departments should be familiarizing themselves with what has already been

accomplished in industrial heating and with modern industrial heating devices and their relation to the general processes of manufacture; and should make preliminary estimates of the amount and distribution of the prospective heating business in their territory; in fact should prepare fully to reap the ripening harvest.

WIRT S. SCOTT

Hitch Your Wagon to a Star

From the standpoint of coal conservation the type of generating unit described by Mr. J. F. Johnson in this issue is of great value. These big units have a steam consumption, with the usual modern steam conditions, of less than eleven pounds per kilowatt-hour over practically the entire load range—a reduction in the last three years of about two pounds. This saving, with attendant economies in the boiler room, has reduced the fuel consumption from two pounds, which was a most creditable performance three or four years ago, to a possible 1.5 pounds with the best modern units.

It is interesting to speculate on what this reduction means to a large generating system. The least efficient unit is naturally the first one to be shut down as the load goes off. This means that the best units will operate almost continuously and will generate much more than their share of the output—probably a large proportion of the total. Assume for example that a central station, which has an annual output of one billion kilowatt-hours, could generate all of its power in units as economical as that described by Mr. Johnson—a condition which is rapidly approaching realization in several cities. At 1.5 pounds per kilowatt-hour this would require 750 000 tons of coal per year, a saving of 250 000 tons per year over the best possible figure of the very recent past.

This however is only one central station and is a comparison between units of maximum efficiency. A conservative estimate would give not over three pounds of coal per kilowatt-hour as an average for the central stations of the United States. Recent estimates give from thirteen to sixteen billion kilowatt-hours as the output from the steam operated central stations of the United States during 1917. Taking an average figure, at three pounds per kilowatt-hour this would require twenty-two million tons of coal. At least half of this coal could be saved for other purposes if all the central station power were generated by units like that described in this issue.

But not all the electric power in the United States is generated in central stations. There are still a large number of private generating plants. Some of these are relatively large and efficient, fully the equal of some of the smaller central stations—but most of them are not. In many of the smaller plants, the industrial or heating requirements for exhaust steam warrant the use of relatively inefficient units—but again with most of them this is not the case. Conservative estimates indicate that at least fourteen billion kilowatt-hours are generated annually in industrial plants, (not including hotels, office buildings, etc.) where the use of exhaust steam is not required, under conditions such that an estimated fuel consumption of 4.5 pounds per kilowatt-hour is conservative. This requires over thirty million tons of coal per year. Of this, one third could be saved if the power were generated in the average central station assumed above; and two-thirds or twenty million tons per year could be saved by generating it all in the most modern stations. Adding to this latter figure eleven million tons which would be saved by bringing all the central stations up to date gives an annual saving of thirty one million tons of coal (about 4.5 percent of the total fuel consumption of the United States) which could be produced by generating all the electric power in the best modern central stations.

Such a saving is of course not all, nor even any large part of it, practicable in the near future. But it is at least an attractive star to hitch one's wagon to.

CHAS. R. RIKER

Our New Department

Domestic electrical heating appliances have been discussed at length in the technical press, and most central stations have conducted educational and advertising campaigns to further their use. However, in spite of the rapidly increasing importance of the subject, relatively little attention has been paid to *industrial* heating applications; and such articles as have appeared have dealt principally with oven and furnace work in which the energy consumption is large. There are many other processes, in which electric heaters have important advantages where the power required for the individual applications is not large; but the aggregate energy consumption of all such applications is surprisingly large, and on this account, and because of the advantages that can only be obtained by the use of electricity, they merit more attention.

In order to give our subscribers the benefit of the engineering ingenuity which is being displayed in such installations, the publication of a section devoted to this subject is begun in this issue. In most cases, the installations described will be suited to a wide range of industrial uses. Where such an installation cannot be used without change in a different industry, it may never-the-less suggest an application of a somewhat modified form. And the month-by-month descriptions of existing successful applications should open up to central station service, new fields where industrial processes may be simplified by industrial heating applications.

Daylight Saving Throughout the Year

Samuel Insull
President,
Commonwealth Edison Co., Chicago

THE FOLLOWING ARTICLE consists of extracts selected, by permission of Mr. Insull, from his address delivered recently before the Electrical Development League of San Francisco. (Ed.)

IF DAYLIGHT SAVING is made effective throughout the year, the day power load and the evening lighting load will not overlap to as great an extent as at present; thus avoiding the sharp peak in the load and thereby releasing plant capacity for other purposes. This plan also affords further saving in coal, as otherwise it is necessary to fire up additional boilers to cover this overlapping peak for a short time in the winter months.

So far as the electric industry of the nation is concerned, the situation is simply this: The seasonal change accorded by the present daylight saving law will result in the saving of coal to the electric companies and in a saving to their customers in electricity consumed; but the electric companies will lose a large amount of revenue, which the saving of coal will not offset. On the other hand, if the change of time be made effective throughout the year, consumers of electricity will enjoy a further saving in electricity consumed, and the electric companies will be distinctly benefited because their day power load and their evening lighting load in the winter months will not overlap as they do now, which will release part of the equipment now necessary.

There is another important benefit that can be gained by a change in time throughout the year, which is lost entirely if the change is made for the summer months only. In many districts, especially where the manufacture of munitions is extensive, the electric companies have been finding their capacity in the winter months inadequate to supply the demands upon them during the period of the day when their power and light loads coincide and, consequently, have been forced to cut off power customers, even to the detriment of the munitions business. This situation would be greatly relieved if the clock could be moved forward one hour during the winter months also, and the Nation, in its present crisis, would be distinctly benefited.

The seven months daylight saving schedule means a saving of about 300 000 tons of coal. The chances are that the all-the-year-around daylight saving schedule would not save much more coal, probably not more than 100 000 to 125 000 tons more.

The annual loss in gross income to the electric companies under the present law is upwards of nine and a half million dollars and the saving in fuel, being the only saving, is about $900 000. The net loss to the companies is somewhere around eight and a half million dollars. Now, if the change in time were made continuous all the year around, upwards of 400 000 kilowatts of capacity would be released, and somewhere around 150 to 200 millions of dollars of capital now employed would be, so to speak, released because, on the whole, the 400 000 kilowatts released by the change in the winter peak could be sold for supplying energy to absolutely necessary industries. The saving in the fixed charge, if a very large amount of additional business could be taken on without increased capital investment, would be from eight to ten million dollars.

Such a scheme put into effect would distinctly conserve between 150 and 200 millions of dollars and would immediately place at the disposal of the Government 400 000 kilowatts of capacity which cannot be found at this time in any other way.

From these figures it is evident that probably no greater effort at conservation of resources, without in any way penalizing anybody, could be made than by the adoption of a yearly change in our daylight schedule instead of a seasonal change. Such an effort of itself would help to maintain the credit of this great business which has today probably three billions of dollars invested in it.

Relation of Transformer Design to Load Factor

S. D. Sprong
Electrical Engineer,
Edison Electric Illuminating Company of Brooklyn

THE electric transformer probably approaches closer to perfection as a converter of energy than any other device in common use and it is no doubt because of our every-day familiarity with it that we seldom stop long enough to appreciate fully its better than 98 percent efficiency and its reliability under unknown and frequently very adverse conditions. It is fortunate that the principles of transformer design are so accommodating as to permit of such an adjustment of losses as to conform more or less to given economic conditions and without materially sacrificing its engineering qualities.

A great deal of time has been devoted to every detail of transformer design and materials and a considerable amount of study to the application of the transformer to particular problems and systems. However,

a large percentage of the total transformers in use are of relatively small capacity and are used on what may be termed "miscellaneous commercial service." While the requirements for such service cannot be stated in exact terms, there are, however, broad generalities that can be drawn from an analysis of systems that are representative of the variety of business connected, the extent of territory and total amount of load of this character.

Of course, an approach to the solution of the problem of the best economic relation of transformer characteristics as distinguished from the purely engineering features, must be by way of first defining in definite terms the requirements of a general system of lighting and miscellaneous power distribution.

Taking as an example, one of the systems with which the writer is generally familiar, it appears that the load factor of the distributing transformers, which range in sizes from one to 50 kw, was on a given date about ten percent. General conditions in the territory suggested that not only should the new business be taken on by employing larger transformer units with extended secondary mains but that many limited areas could be consolidated by developing a more or less general secondary main system and in some cases, an inter-connected network of secondary mains.

Careful consideration of districts of this character will show many distinct advantages for investment made in secondary mains over the equivalent in smaller and more numerous transformers. On an average cost of energy and transformer investment, the transformer requires from six to eight percent of its investment in yearly energy loss; this in addition to the usual investment, depreciation and repair accounts. On the other hand, an extension of secondary mains to what, at the time, might appear unjustified distances, has the advantage first in securing greater diversity factor and thereby increasing the load factor on the transformers; second, reducing energy loss per kw-hr. sold, and third the investment in secondary mains is largely in copper and a relatively small percentage in insulation, with the result that there are very small carrying charges as far as depreciation, obsoletion or repairs are concerned, in addition to the interest on the original investment.

Careful study of the map of a territory with location and size of transformers indicated thereon, will show many sections where, in the light of the above considerations, a number of secondary extensions should be made, with resulting additional advantages such as a wider choice in the location of the transformer, usually permitting its removal from the more congested section of pole line and minimizing the number of points for inspection in case of trouble. Other advantages of such changes are, in addition to the elimination of a large number of small and more or less obsolete transformers, the adoption of a standard size of say 50 kw, and at some later time the tying together in a general network of the more or less isolated sections supplied by single large unit transformers as the business in the intervening area develops.

The most important result of carrying forward such a policy over a five year period is shown by comparison of the results obtained during the interval.

The load factor, as stated, at the beginning of the period was about 10 percent and at the end of five years had increased to 14 percent, or a 40 percent improvement. Along with this improvement in load factor, there was a reduction in investment in street distribution equipment per kilowatt demand of about 32 percent, due largely, but probably not entirely, to the increase in the average load factor on the transformers, and the lower cost per kilowatt in transformers and fittings when combined in larger units. This is the net result after taking into account the additional cost to cover the secondary extensions.

The above comparisons may perhaps suggest to designers as well as the users of transformers in territories of the character described that the distributing transformer is theoretically not best proportioned to the economical requirements of the problem. This refers, of course, to the ratio of iron and copper losses which, on an assumption of 15 to 20 percent load factor (and it is improbable that it will go much higher in the majority of cases), should have a ratio of about six to one for copper and iron loss respectively. Such a ratio indicates somewhat poorer regulation and higher copper temperatures at full load.

Regarding the question of regulation, this is more easily taken care of where transformers are used in networks and, with present methods of automatic compensation and regulation, should introduce no serious difficulty.

The copper temperatures have been largely limited by cellulose insulation, and insulating oil, but with the newer forms of insulation now available, which safely withstand higher temperatures without impairment of dielectric value, it may be desirable to consider a reversion to the old air-cooled form, if it is impossible to find any fluid insulator that will remain stable under the higher temperatures.

A transformer designed to meet the conditions described would reduce present transformer losses by about 25 percent. While this is theoretical, it indicates the possibilities of the future and it is to be hoped that, with the present-day knowledge of materials, it will be possible to modify transformers so as to parallel more nearly the economic requirements in this particular class of service.

The New Commonwealth Edison Turbine

J. F. Johnson
Turbine Engineering Dept.,
Westinghouse Electric & Mfg. Co.

THE TANDEM COMPOUND turbine-generator unit recently installed in the Northwest Station of the Commonwealth Edison Company of Chicago is the largest single shaft, single generator unit built by the Westinghouse Company. The whole installation, including the surface condensing equipment, contains new and interesting features of design. This unit has been in regular operation since October, normally carrying loads of from 20 000 to 30 000 kw, with peaks as high as 37 000 kw. It comprises a tandem-compound turbine consisting of separate high-pressure and low-pressure elements on a continuous shaft, designed for 220 lbs. gage steam pressure, with 200 degrees F. superheat at throttle, and an absolute pressure of one inch mercury at the exhaust; driving a 35 300 k.v.a., three-phase, 60 cycle, 12 000 volt generator, with a 160 kw, direct-connected exciter, at 1200 r.p.m., and is served by a 56 000 sq. ft. surface condenser built in two shells of 28 000 sq. ft. each, and capable of maintaining 29 inches vacuum at 30 000 kw load with 58 degrees F. circulating water.

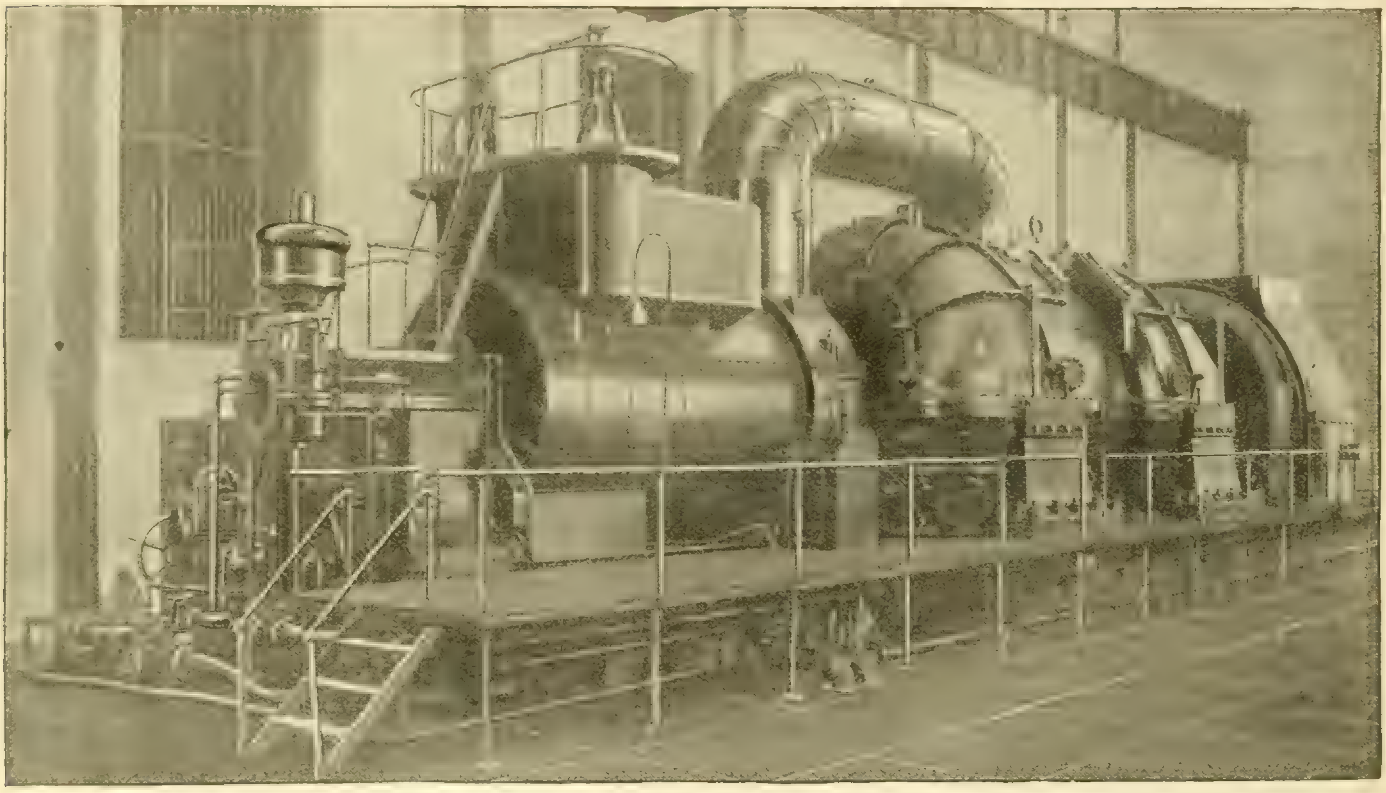

FIG. 1—35 300 K. V. A., THREE-PHASE, 60 CYCLE, 12 000 VOLT, 1200 R. P. M. TANDEM-COMPOUND TURBINE GENERATOR
Installed in the Northwest Station of the Commonwealth Edison Company, Chicago.

Among the first questions suggested concerning this unit are, "Why was the turbine made tandem compound?" "Why were new features of design used?" "Why was it not similar to previous units of slightly smaller capacity?"

In turbines of smaller size, the general design is arranged to best meet general conditions, and without regard to any particular installation or purchaser. The larger machines, however, are more or less built to order. The design is determined upon as the result of negotiation, and is arranged to meet the industrial needs and personal preferences of the purchaser. Considerable variation in designs of large units is therefore to be expected, not only because of the diversity of actual requirements or industrial conditions of the various power generating stations, but also because of the newness of the industry. Nearly every large power station today is, to a greater or less extent, a pioneer institution in which many new problems have to be dealt with, and many new and improved designs and arrangements of apparatus, usually involving larger capacities, have to be developed and perfected.

The present unit was designed for the maximum reliability and efficiency that is possible with the turbine driving a single generator capable of delivering 30 000 kw continuously at 85 percent power-factor, to have highest efficiency at loads between 20 000 and

30 000 kw, and to be able to carry 35 000 kw for short periods. The speed of 1200 r.p.m. was chosen because it permitted employing ample blade lengths and areas to expand the steam efficiently to 29 inches without exceeding blade speeds and stresses previously used, and known to be safe and conservative. It also permitted employing standard design and materials in the generator without compromise.

The turbine is of new design but of standard reaction type construction. No impulse element is employed because, for the given conditions, its efficiency would be materially poorer than that of the shortest reaction blading, and there would be no other advantages sufficient to justify its use. Two separate turbine elements are employed to carry out the steam expansion in order that blade lengths and diameters conducive to the highest efficiency may be used and still permit the physical dimensions of the turbine structure and the distance between bearings to be suitably proportioned to obtain the maximum degree of ruggedness and reliability. Another important feature of this construction is the reduction of temperature difference existing between the inlet and exhaust portions of each turbine element.

When operating at its point of highest efficiency, which is at 25 000 to 26 000 kw, the steam enters the high pressure element at approximately 225 lbs. absolute and a temperature of 594 degrees F. and leaves it at a pressure of approximately 30 lbs. absolute and a temperature of 258 degrees F. It leaves the low pressure element at a pressure of one inch Hg. absolute and temperature of 79 degrees F. The maximum temperature difference in the high pressure cylinder is therefore 336 degrees and in the low pressure cylinder 179 degrees. At loads greater than 25 000 kw, this temperature difference decreases in the high pressure element and increases in the low.

Since in the reaction-type turbine all the blades, both rotating and stationary, are virtually nozzles in which steam expansion takes place, 126 pressure stages are employed in expanding the steam from throttle pressure to condenser pressure. The area of the steam passage through each row is proportioned to give the desired pressure drop and steam velocity. The proportions of total power developed in the high and low pressure elements are approximately 42 and 58 percent respectively.

High design factors, liberal steam passages, and the best known mechanical construction, have been used. The blade sections are materially wider and heavier than are usually employed by builders of reaction turbines.

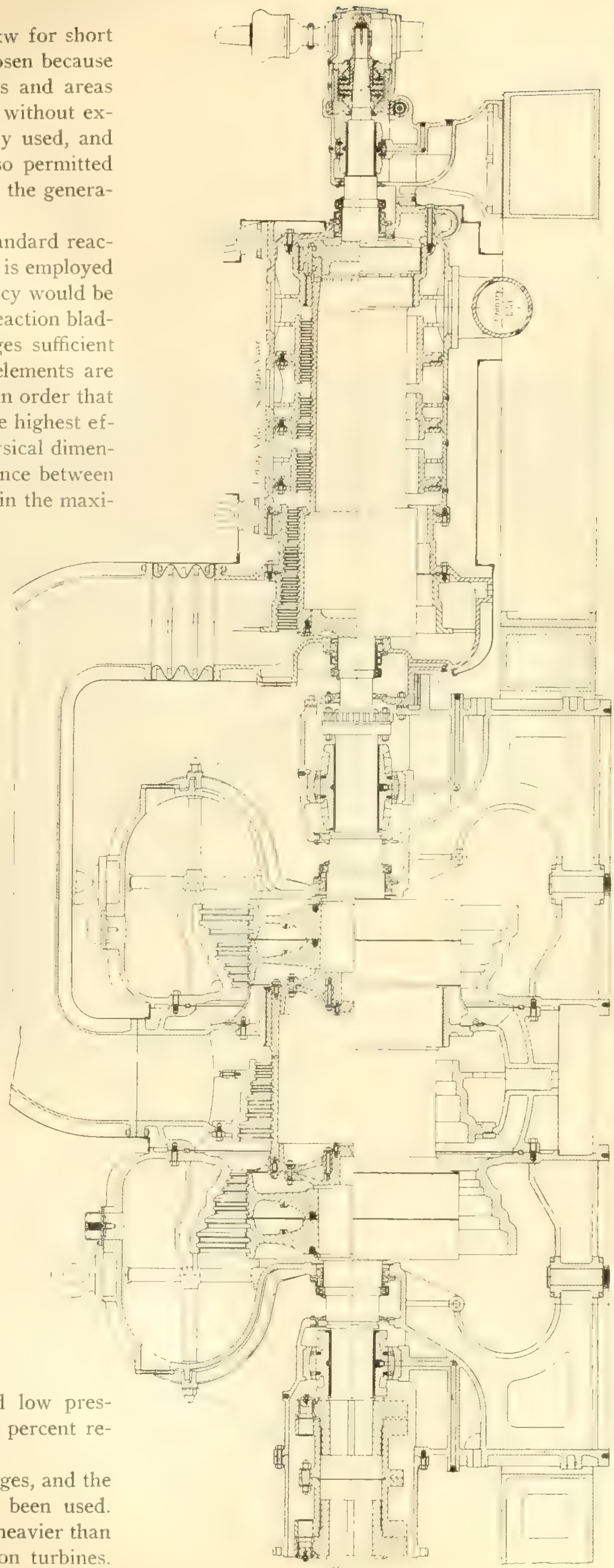

FIG. 2—SECTION OF THE 35 300 K. V. A. STEAM TURBINE

The steam expansion is divided in two elements with the cylinders arranged in tandem.

Increased rigidity and durability are thereby secured. All blades are profiled or reduced in thickness at their free ends so that, in case of contact between stationary and rotating elements due to failure of bearings, or improper adjusment, no serious damage to either blading or blade carrying elements will result. The most prolific cause of blade failure in steam turbines of all types is blade vibration caused by the flow of steam. This has been reduced to safe limits by lashing the blades together, a sufficient number of lashings being employed so that the length of free blade section in no case exceeds six inches. In the 18 inch low-pressure blades, three lashings are used. The blade speeds and consequently blade stresses employed are low, the maximum mean speed being 513 feet per second, the minimum 210 feet per second.

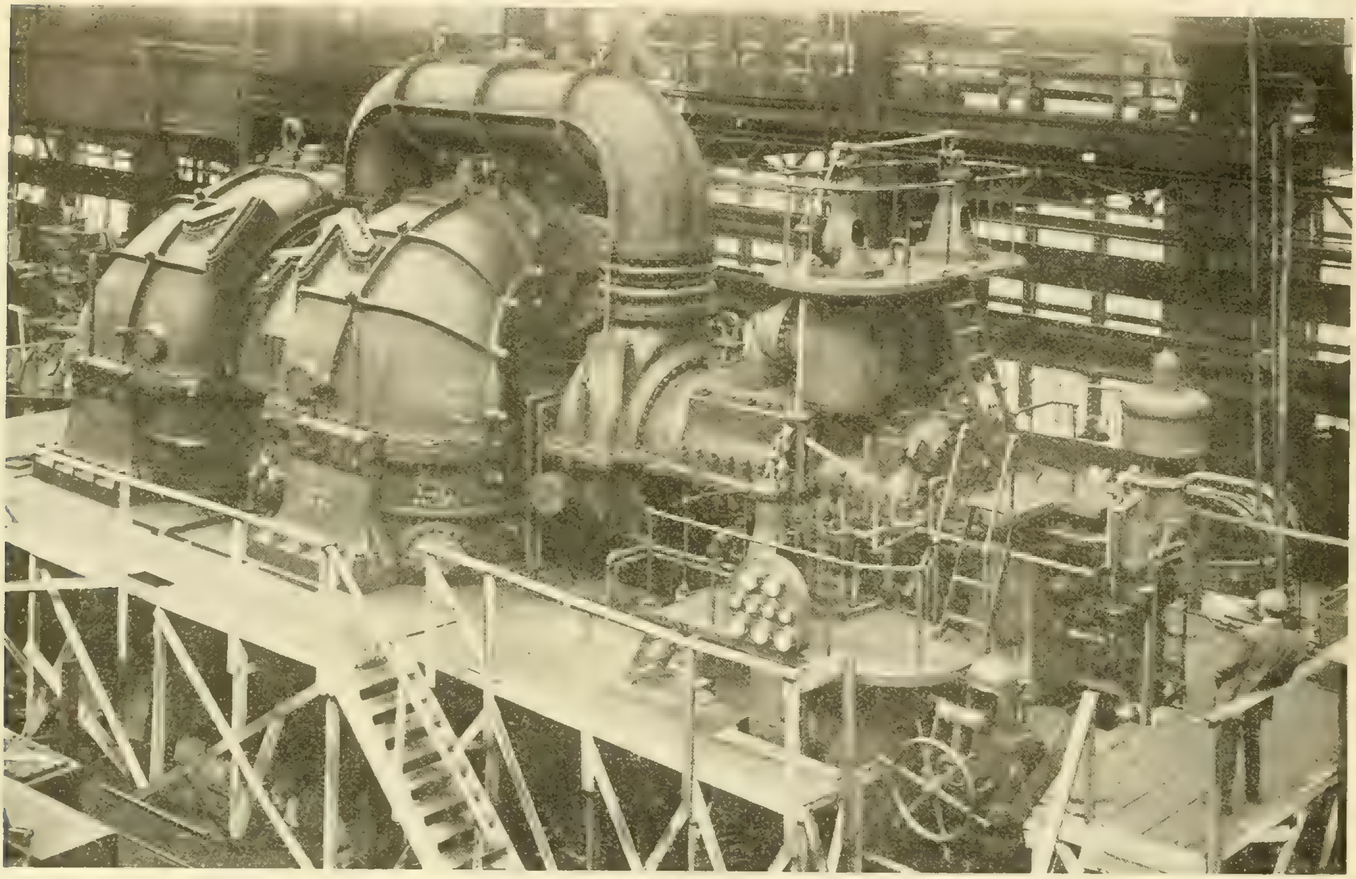

FIG. 3 TURBINE ASSEMBLED ON TEST FLOOR

MAIN BEARINGS AND COUPLINGS

The rotating elements of the turbine and generator are carried on five main bearings, three being on the turbine and two on the generator. In addition to these a double Kingsbury thrust bearing is mounted on the free end of the high pressure rotor just outside the main bearing to maintain the correct longitudinal alignment and also to carry the unbalanced portion of the end thrust. Of the three main turbine bearings, two are on the low pressure element and one on the high pressure. The exhaust end of the high pressure rotor is carried on the adjacent low pressure bearing, the two rotor shafts being connected by means of a solid flanged coupling, the flanges of which are integral with the shafts. Between the low pressure turbine and generator, a standard flexible pin type coupling is used. This is believed to be the most perfect type of flexible coupling known for the purpose and has important advantages over the solid claw type, which it replaced. Sufficient elasticity is provided in the pins to distribute and absorb the shocks produced by heavy short-circuits without danger of injury to the coupling; and both contact surfaces, that is the pins and bushings, are renewable in case of excessive wear due to prolonged operation with improper alignment or poor balance of one of the rotating elements.

At first glance it might appear that the three-bearing construction for two turbine elements would render the adjustment of clearances and alignment difficult and complicated. This, however, has been given consideration in the design and means provided whereby the operation becomes quite simple. To carry the exhaust end of the high pressure spindle, when the coupling between the two elements is disconnected, a short alignment bearing is provided to be substituted for the lower half of the oil baffle ring, between the coupling and the gland. This bearing is provided with liners similar to those used on the main bearings for adjusting its position. With the coupling disconnected and this align-

ment bearing in place, regular clearances can be taken on the high pressure and low pressure elements separately, and each rotor set in the correct position with relation to its stator. This having been done the whole high pressure element may be raised or lowered, or moved sidewise at either end until the two coupling flanges match up perfectly. Liners are provided underneath the cylinder support at each end to facilitate this adjustment, which, when once made, will seldom, if ever, require changing.

The exhaust end of the high-pressure cylinder is supported on the low-pressure cylinder as close as possible to the low pressure bearing support. This is done so that any slight change in the position of the high-pressure rotor, due to a temperature change in the low-pressure bearing support, will produce a corresponding change in the position of the high-pressure cylinder. The position of the rotor with reference to its cylinder must therefore remain constant under all conditions. Longitudinal expansion of the turbine cylinders is provided for by rigidly attaching the low pressure cylinder to the bedplate at its generator end only, and leaving the other end free to slide on the cylinder supports while the pedestal under the governor end of the high-pressure cylinder is free to slide (longitudinally only) on the bedplate. The amount of movement at the high pressure pedestal in changing from cold to normal operating temperature is approximately 5-16 inch.

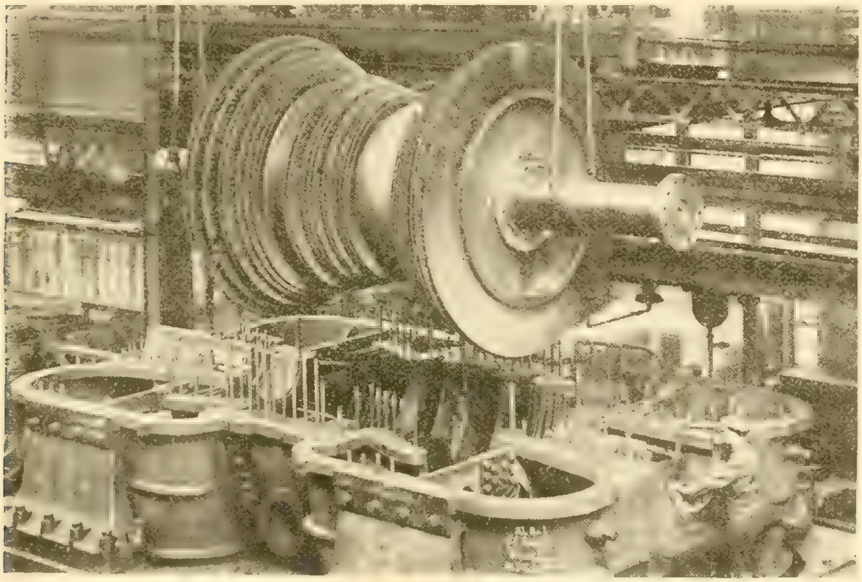

FIG. 4—LOW-PRESSURE ROTOR BEING LOWERED INTO LOWER HALF OF STATOR

MAIN BEARINGS

The main bearings are heavy cast-iron shells, split horizontally and lined with babbit. Each bearing is fitted with four large spherically machined pads, (one each at top and bottom and either side), which fit a spherical supporting ring in the housing. The bearing, therefore, has perfect freedom to align itself to the journal and the pressure is equally distributed. Underneath each of the four spherical pads, a number of sheet steel liners of various exact thickness are placed to provide an easy, quick and accurate means of changing the alignment of the rotating element. For example, if it is desired to change the alignment of a bearing 0.010 inch either vertically or horizontally, a 0.010 inch liner is removed from underneath one pad and placed underneath the one opposite.

The journal speeds and bearing pressures employed are sufficiently low so that water cooling in the bearings is not required. The maximum speed is 95 feet per second, and the pressure per square inch of projected area 105 lbs. The temperature of the oil leaving the bearings normally varies between 130 and 150 degrees F. The oil is admitted to the bearing through an opening in the top supplying a large oil groove running the entire length of the bearing. Although an oil pressure of approximately five lbs. is normally carried on the bearings, only sufficient pressure is required to keep the oil groove in the top of the bearing filled. There is therefore no danger of bearing failure from decreasing oil pressure until the oil actually ceases to flow to the bearing.

GLANDS

Combination labyrinth and water glands are provided on both high pressure and low pressure elements to prevent leakage of steam or air where the rotor shafts pass through the cylinder casings. These constitute an ideal sealing arrangement in that they are absolutely tight against air leakage into the turbine and steam or vapor leakage into the room. They require no adjustments for varying load conditions and do not depend on the operation of any automatic devices. There is no mechanical contact between stationary and rotating parts and therefore no wear. They are extremely simple in design, require no special attention, and are as durable as any other part of the machine. The steam labyrinths on the low-pressure element are used only for starting up. By admitting high-pressure steam into the chamber between the two sections of labyrinth in sufficient quantity to keep the pressure in this chamber several pounds above atmospheric, a vacuum may be established in the condenser before starting the turbine. As soon as sufficient speed is attained to enable the water glands to seal, which is somewhere between ½ and ¾ normal speed, the gland water is turned on and the steam to the labyrinths shut off. The labyrinths on the high pressure element, when starting up, are operated in the same manner as are those on the low pressure and perform the same function. They, however, perform the additional function of reducing the steam pressure at the water glands when the machine is in normal operation. In construction they differ from the low pressure only in that they are separated into three sections instead of two, thus providing two enclosed

annular chambers. The chambers nearest the water glands are piped up to the same high-pressure steam supply as are those on the low-pressure, and steam is admitted to them when starting up only. The other chambers are connected by piping to an intermediate stage of the low-pressure turbine where the pressure does not materially exceed atmospheric. When the

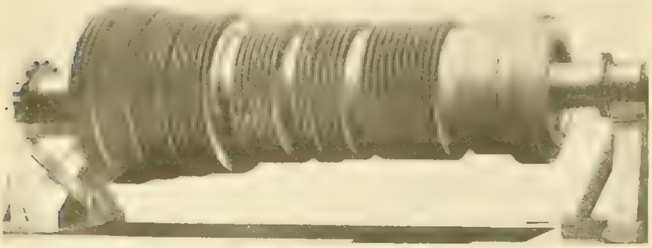

FIG. 5—HIGH PRESSURE ROTOR

turbine is in normal operation, then, and the pressure inside the cylinder at both ends increases with the load to a maximum of approximately 30 lbs., the steam leakage past the inside section of the labyrinth is led to the low pressure element and thus the pressure on the water gland is kept within the limits against which it has been designed to seal.

OILING SYSTEM

A complete oil circulation and cooling system of 1000 gallons normal operating capacity is provided as a part of the turbine unit. Pure mineral oil of approximately 150 seconds Saybolt viscosity at 100 degrees F. is used. The oil is circulated at 150 gallons per min. and is supplied to the bearings under a pressure of five lbs. A portion of it, however, is used under a pressure of from 50 to 60 lbs to operate the governor-controlled inlet valves. Besides the necessary piping, valves, etc., the oiling system includes:—

1—A double pressure reciprocating oil pump driven from the high pressure turbine rotor.

2—A duplex direct acting steam driven auxiliary pump for starting.

3—A surface type cooler.

4—A reservoir.

5—A strainer box.

OIL PUMP

A reciprocating plunger pump is used because it is better adapted for pumping against high pressure and ready accessibility of the important parts may be had for inspection or repair without complete dismantling. The plungers are of two different diameters, the smaller one supplies oil to the valve operating mechanism at 50 to 60 lbs., and the larger one discharges direct to the bearings through the oil cooler at approximately five lbs.

OIL COOLER

All of the oil cooling is done in an oil cooler* containing 600 sq. ft. of cooling surface, which in design is somewhat similar to an ordinary surface condenser. The cooling water passes through the tubes, making a sufficient number of passes to raise the temperature of the water very close to that of the outgoing oil, thus requiring a minimum quantity of water. The oil passes around the tubes, suitable baffles being provided to secure even circulation which is necessary for effective cooling.

Possibly the most important feature of this cooler is its accessibility for cleaning. By simply unbolting and removing the cooler box cover and disconnecting two small unions on the water connections, the entire nest of tubes may be lifted out, the tube plate covers removed, and the tubes thoroughly cleaned both inside and out. The tubes being straight, mud or scale can be thoroughly and quickly removed. Coolers or cooling coils which have curved or irregular water passages are not susceptible of thorough cleaning, hence their original effectiveness cannot be maintained unless absolutely pure water is used for cooling.

OIL RESERVOIR

The oil reservoir is a rectangular box attached to the side of the bedplate. It has sufficient capacity to take care of reasonable variations in the quantity of oil in the system, and to afford an effective settling chamber for the separation and removal of impurities. It receives the oil from the strainer box at one end and delivers it to the oil pump at the other. The oil velocity through it being very slow, any foreign matter or impurities heavier than oil will settle to the bottom, and be prevented from getting into the pump suction. A suitable automatic overflow drawing from the bottom of the reservoir is provided for connection to a gravity or partial filtration system. For every gallon of clean oil admit-

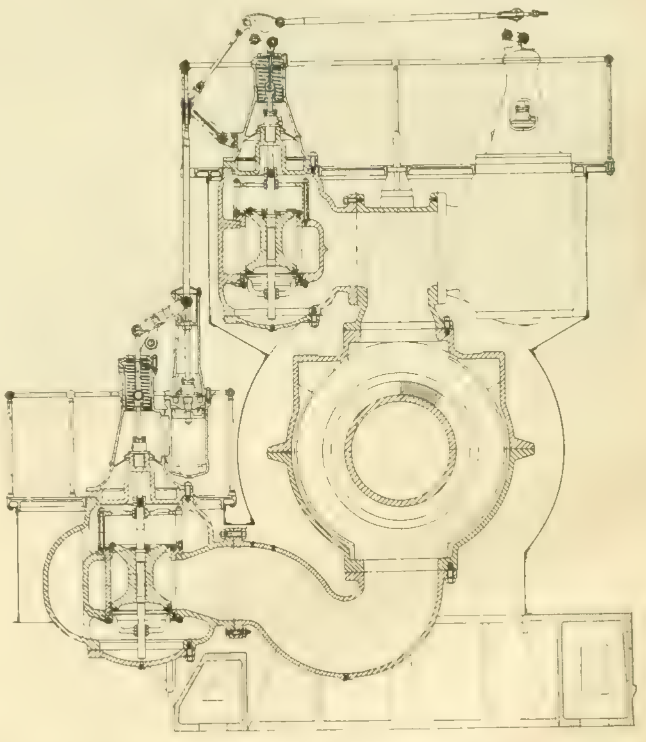

FIG. 6—SECTION THROUGH GOVERNOR-CONTROLLED INLET VALVES OF HIGH-PRESSURE TURBINE

*See article on "Steam Turbine Progress" by Mr. Francis Hodgkinson in the JOURNAL for April '18, p. 131, Fig. 30

ted into the system, a gallon of dirty oil will be discharged from the bottom of the reservoir. The turbine oiling system therefore, while it may be continually receiving clean oil from and delivering dirty oil to a gravity or partial filtration system, is entirely independent of the operation of that system.

OIL STRAINER

The oil strainer is a rectangular cast-iron box, mounted on the side of the bedplate adjacent to the oil reservoir, containing three flat screens which extend entirely across it. It is open at the top but contains a loose cover. The strainers are several inches higher than the normal level of the oil and are open at the top so that if they are not kept clean the oil level will rise until it overflows them. The condition of the screens may be determined at any time by removing the strainer box cover and observing the difference of oil level on opposite sides of them. When dirty, they may be lifted out by hand and cleaned with compressed air or water. The operation of the oiling system is as follows:—From the reservoir the oil flows to the main oil pump by gravity; the oil level in the reservoir always being higher than the center line of the pump. The discharge from the low pressure side of the pump goes to the oil cooler and from there directly to the bearings. The discharge from the high pressure side goes to the valve operating mechanism on the steam chest through a surge tank located as close as possible to the steam chest. The surge tank provides a quantity of oil under air pressure sufficient to take care of any sudden heavy demand from the valve mechanism, and maintains the discharge head on the pump practically constant during the varying demands. The oil discharged from the valve mechanism unites with the oil discharged from the low pressure side of the pump before it enters the coolers. All of the oil from both sides of the pump is therefore used for lubrication of the bearings. A spring loaded pressure relief valve bypasses the valve operating mechanism to afford a passage for the surplus high pressure oil not required for operating the valves.

HIGH-PRESSURE TURBINE

The high pressure turbine is of the single-flow type because the steam volumes are relatively small. It contains forty-five rows of rotating blades and an equal number of stationary rows. The length of the shortest blades is four inches, and the width one inch, consequently the losses in them are very small and the net efficiency materially higher than would be obtainable with a two-velocity-stage impulse element. High pressure steam is admitted to the turbine cylinder by the primary governor-controlled inlet valve, and at all loads up to 25 000 kw enters the first row of blading, and passes successively through all the rows to the exhaust. At loads between 25 000 and 30 000 kw a secondary valve opens, bypassing the first section of blading and admitting high pressure steam direct to the twelfth stationary row. At loads beween 30 000 and 35 000 kw, a tertiary valve also opens, bypassing the first two sections of blading, admitting high pressure steam direct to the nineteenth stationary row. At the extreme front end of the spindle body are two balancing pistons provided with labyrinth packing to partially balance the end thrust, caused by the differences of pressure on opposite sides of the rows of rotating blades. The pressure between the balance pistons is maintained equal to that between the two rotor diameters and the pressure against the governor end of the rotor is maintained equal to that against the exhaust end by means of suitable equalizer connections.

The Rotor is made in three parts from special high grade steel castings. The two ends are attached to the body or drum by means of long spigoted press fits reinforced at the exhaust end with specially constructed fillister head tap bolts, and at the governor end with shrink links.

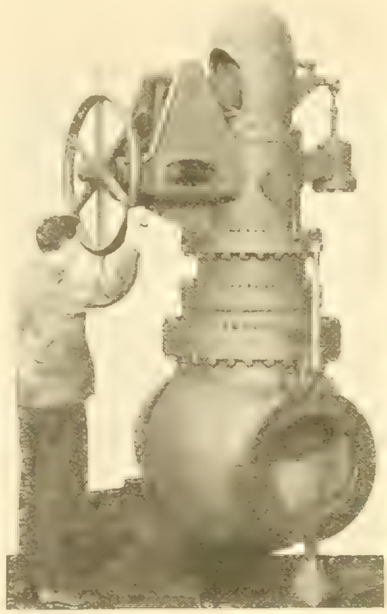

FIG. 7—20 INCH COMBINATION THROTTLE VALVE

The Stator is made of cast steel. It is divided up into a number of assembled parts so that castings as plain and simple as possible may be used, insuring the best possible quality of material, and so that the greatest freedom from shrinkage and other distortional stresses may be secured. The joints between the assembled parts are accurately surfaced and bolted up metal to metal, no gasket material or its equivalent being used. Keys or spigoted fits are employed to insure accurate and positive doweling. The horizontal joint between the upper and lower halves of the cylinder is also accurately surfaced and bolted up, metal to metal, the bolting everywhere being heavy and closely spaced to insure against distortion and leakage.

BARRING-OVER DEVICE

A barring over device, engaging ratchet teeth machined in the circumference of the coupling flange, is provided to facilitate turning the rotor for inspection or for disconnecting the couplings. On the free end of the rotor shaft there is keyed a steel worm which drives

a gun metal wheel, mounted on the governor spindle, at 309 r.p.m. The oil pump is driven from the governor spindle by means of a spur gear and pinion at 169 r.p.m. The worm is held on the spindle by means of a special nut which contains the overspeed governor. This governor is adjusted to come into operation at approximately 1320 r.p.m., closing independently both the main throttle valve and the primary inlet valve.

GOVERNING MECHANISM

The governing mechanism has been designed and built with the conviction that it is the most important feature of the unit. It is extremely sensitive, positive, and quick to adjust itself to small or large changes in load. The arrangement of the three governor controlled inlet valves and their control mechanism, is new, but the method of operation and control is identical to that employed on all large turbines built by the Westinghouse Company. In the design of any turbine of any type, prolonged satisfactory operation is not to be expected unless the arrangement of inlet valves and steam piping be such that changing temperature conditions will not impose heavy stresses on the turbine. Consequently in this design the secondary and tertiary valves have been separated from the primary and mounted on top of the cylinder where the pipe connections can be

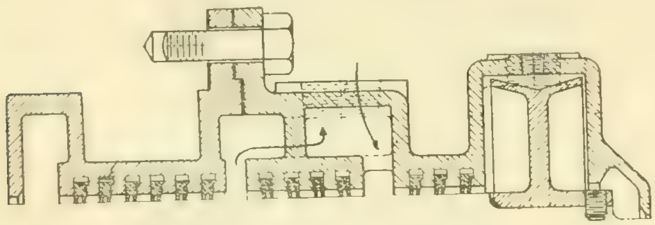

FIG. 8—SECTION THROUGH ONE SIDE OF HIGH-PRESSURE GLAND

made shortest and where variations in stresses, due to changing conditions, will be a minimum.

The primary valve, steam strainer, and throttle valve, which must of necessity be located in the main steam connection exterior to the turbine, are mounted on coil spring supports attached to the bedplate, the design being such that the springs carry the weight of the valves and still permit them to move in any direction with the turbine cylinder. The valves are all of the double-seated balanced type with renewable monel seats and rings. The valves proper and bodies are made of cast steel. The three valves are operated in series by means of a high pressure oil relay mechanism, the secondary valve being adjusted to begin opening when the primary inlet pressure reaches its maximum, and the tertiary to begin opening when the secondary inlet pressure reaches its maximum.

The governor is of the fly-ball type. It is intentionally made very large and powerful so that it can handle the oil relay control valve under all conditions with ease and accuracy. Theoretically, with almost any reasonably designed governing mechanism there will be a definite change in load for any change in speed, however slight. Practically, however, governor linkages are never frictionless, nor absolutely free from lost motion, and multiport relay control valves will never have their ports absolutely accurate; consequently there will have to be sufficient change in speed to overcome these imperfections before there will be a movement of the valves. Furthermore, the oil in a long pipe has considerable inertia even when under high pressure and does not instantly respond to the opening of the control valve. In this governing mechanism, the linkage adjacent to the governor is given a small, positive, oscillating motion, sufficient to overcome any lost motion in the linkage and error in the accuracy of the relay control valve, and still cause a very slight oscillation of the main inlet valves; consequently the slightest change in speed will be responded to by the valves. The sluggishness caused by the inertia of the oil is overcome by installing a high-pressure bypass relief valve as close to the oil operating cylinder as possible, and employing a positive oil pump so that the oil in the supply and discharge lines is flowing continuously except in the

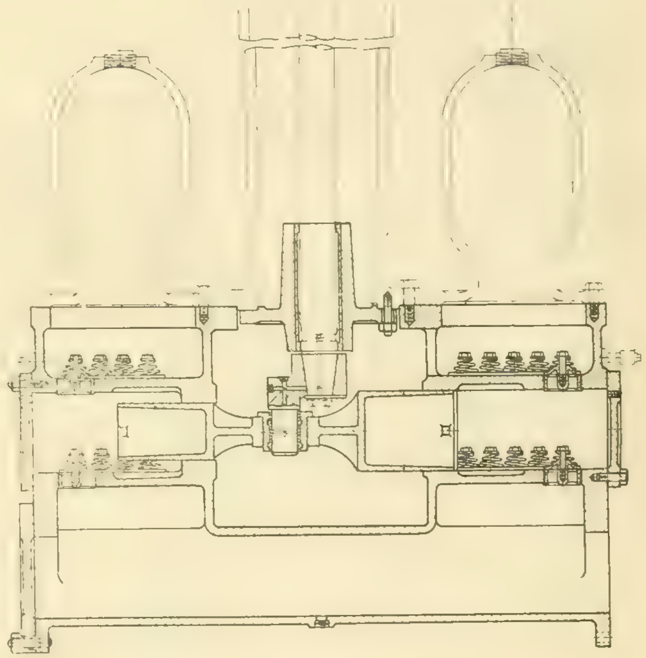

FIG. 9—SECTION THROUGH OIL PUMP

short connections between the bypass valve and the operating cylinder.

LOW PRESSURE TURBINE

The low pressure turbine is of the single-double-flow type, because the change in steam volume taking place within it is very large. The volume of the entering steam at average load is 13 cubic feet per pound, and at exhaust is 585 cubic feet per pound. Steam from the high pressure element enters through the overhead connection and passes through ten stationary and ten rotating rows of single flow blading. It then divides, half going straight on through the eight stationary and eight rotating low pressure rows to one exhaust, and the other half passing around the intermediate section between the inner and outer cylinder, and through a similar low pressure section to the other exhaust. A labyrinth packing is interposed between the inlet cham-

ber and the low pressure section opposite to the intermediate section to prevent entering steam from passing directly to the low pressure stage. The length of the shortest blade is nominally six inches and the longest 18 inches.

The Rotor is made entirely of steel and is designed to secure maximum rigidity with minimum weight. It is built up of a hollow drum carrying the single-flow section blading and labyrinth packing rigidly attached to two shaft ends. Upon each of these shaft ends are mounted two discs carrying the double flow section of blading.

The Stator is made entirely of cast iron, the temperature and mechanical stresses being sufficiently low that steel is not required. It is made up of a central section and two end sections keyed and bolted together. Each of these sections is split horizontally, the top half of all three being normally handled as one piece. The intermediate stage blading is carried on one inner cylinder which is separated from the outer cylinder sufficiently to provide space for passage of the steam to one of the double-flow sections. On account of the

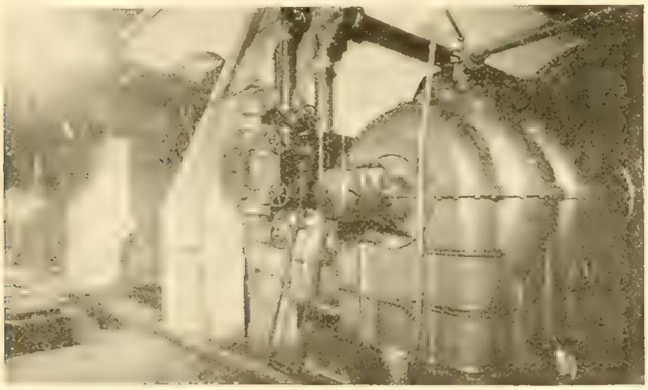

FIG. 10—56 000 SQUARE FOOT SURFACE CONDENSER AND CIRCULATING WATER PUMPS

great size of the end sections, an elaborate system of bracing is employed to secure absolute rigidity against collapsing stresses due to the vacuum, and to maintain the position of the blade carrying elements absolutely fixed with reference to the bearing supports. An auxiliary steam inlet is provided through which a limited quantity of exhaust steam at atmospheric pressure, not required for feed water heating, may be admitted direct to the low pressure stages. Roughly, for every 2.5 lbs. of steam admitted through this connection, one pound of high pressure steam will be saved.

CONDENSING EQUIPMENT

The 56 000 square foot surface condenser is built in two separate shells, each directly connected to one of the low pressure turbine exhausts without the medium of an expansion joint. Nearly the entire weight of the condensers is carried on helical spring supports. Rubber expansion joints are provided in the water and air lines so that the condensers may be free to move with the turbine without causing excessive stresses in it. This design obviates the use of expansion joints in the main exhaust connections and keeps the stresses on the turbine structure constant under all conditions, but is open to the objection that the condensers might at some time be accidently prohibited from moving freely with the turbine, which might result in more or less serious damage. Each shell contains 6486 one-inch tubes, 16.5 feet long, and in addition a primary heater containing 750 sq. ft. of heating surface located in the top of the shell.

In regular surface condensers of such size, the temperature of the condensate is from 10 to 15 degrees F. lower than that of the steam entering the condensers. The function of the primary heater is to heat the condensate which passes through it on its way from the condenser to the feed water heater to within two or three degrees of the temperature of the exhaust steam entering the condenser.

Circulating Water to the two condensers is supplied by one 60 000 gallon per minute motor-driven centrifugal pump. A very small portion of this water is taken from the pump discharge for the turbine oil

FIG. 11 LE BLANC AIR PUMPS AND CENTRIFUGAL CONDENSATE PUMPS

cooler. There are two turbine-driven combination air and condensate pump units, each connected to both condensers. They are of sufficient size so that under normal conditions only one need be operated. The air pumps are of standard high-speed Leblanc type, each unit consisting of two double elements. The condensate pumps are of the standard two runner single stage centrifugal type.

A duplicate of the above described unit is at present being installed in the Northwest Station, and a third of similar capacity, but designed for twenty-five cycle service, is being built for the Fisk Street Station.

THE GENERATOR.

The main generator is unusual only on account of its size; otherwise it is of standard construction. It is rated at 35 300 k.v.a. (30 000 kw at 85 percent power-factor) three-phase, 60 cycles, 12 000 volts, 1200 r.p.m. and is capable of delivering its rated k.v.a. output at any voltage between 11 500 and 12 600.

The axial ventilation system is used for the stator. Cooling air is passed through openings in the iron par-

allel to the shaft, and discharged from an annular central duct into the frame casing. This arrangement allows the use of the shortest possible rotor, increasing the stiffness of construction and hence insuring freedom from vibration. Further, from a cooling standpoint, it permits of the most intimate contact of the air with the iron, and since the heat conduction is greatest along the plane of the laminations, any tendency toward hot spots in the iron is reduced to a minimum.

The cooling air is supplied by a ventilating fan, capable of delivering 110 000 cubic feet of air per minute against 5.5 inch water head, and driven by a

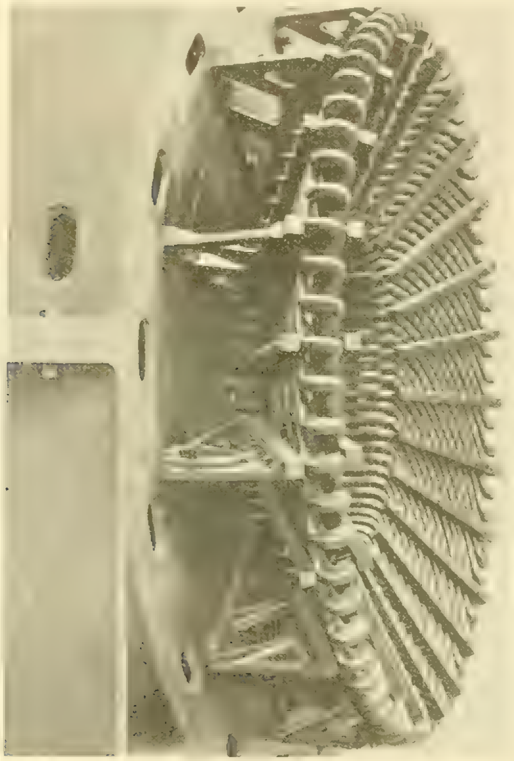

FIG. 12 ARMATURE COIL BRACING

200 hp. three-phase, 60-cycle, 440-volt, 500 r.p.m. wound-secondary induction motor. The principal arguments in favor of a separate fan for cooling are,—somewhat better fan efficiency and material reduction of noise in the station, as well as a possibility of using higher air velocities in the intake ducts and through the turbine. In the generator proper, it is possible to make a reduction of approximately two feet in the over-all dimensions, if a separate fan is employed.

The rotor construction is of the so-called plate type, in which discs approximately two inches thick are rabbeted into each other and strung upon through-bolts at their outer periphery. This construction insures the working of the metal in a tangential direction, as well as guaranteeing a uniformity of steel throughout the whole body, and eliminates internal stresses due to unequal heat-treatment which are liable to occur with large diameter steel forgings.

The insulation of both stator and rotor is good for a temperature of 150 degrees C. continuously. This temperature is measured on the stator by means of embedded detectors located in the winding; and on the rotor by the increase in resistance of the field coils. Such a high temperature guarantee necessitates the use of the best grade of insulation, as only that grade will withstand the temperature specified. The guarantee also acts as a guide to the operator for overloads under emergency conditions of operation, indicating the margin of safety on the machine. Taken in conjunction with the proved fact that mica insulation is good for temperatures considerably in excess of 150 degrees, this guarantee indicates ample margin of safety in insulation temperatures. The extent of this margin is indicated by the fact that in this particular unit a maximum temperature of 114 degrees has been secured at full rated load with 25 degree air. An added advantage of the use of mica for insulation is its proved ability to withstand without injury corona or static discharges. Such discharges exist to a certain extent with practically all machines wound for 10 000 volts and higher. Static is accompanied by the formation of nitrous oxide and similar chemical compounds, which attack all insulating materials of fibrous nature with disastrous results.

These machines are guaranteed to withstand direct short-circuits without injury to the stator winding. This necessitates a very rigid bracing of the stator coil. Movement of any coil is prevented by supporting the coil in a series of clamping devices such as those shown in Fig. 12, which restrict its motion in all directions.

The direct-connected exciter for this unit is of more than sufficient capacity to provide an ample safety factor. The rating is 160 kw, 230 volts, 1200 r.p.m., shunt-wound. The full load excitation of the main turbine is less than 500 amperes. A special condition of operation is that no rheostat is used in the main generator field, and the shunt-wound exciter will deliver steady voltage at any point in the range of 100 volts to 230 volts. This condition is satisfactorily met by special proportioning of the magnetic circuit of the exciter so as to secure a certain degree of saturation throughout the entire voltage range.

Mazda Lamps for Motion Picture Projection

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THE experimental work of the various lamp companies during the past few years has resulted in the production of Mazda lamps which are suitable for the projection of motion pictures. Not every requirement can be met but, in a large number of cases, the conditions are such that Mazda lamps give results which are superior to the results obtainable from existing electric arc equipments. Wherever an alternating-current arc is used there is a possibility of substituting a Mazda lamp, and in some cases where small direct-current arcs are used the Mazda lamp will also give improved pictures.

The principal advantages of the Mazda lamp may be outlined briefly as follows:—Perfectly steady light; permanent focus; better color tone of the picture; no carbon dust to scratch the film and cause wear on the bearings of the machine; reduced breakage of condensers. In most cases the power cost is reduced; however, the essential thing to be considered in the application of Mazda lamps for motion picture projection is the picture which is projected on the screen. Unless the results obtained are eminently satisfactory and a pleasing picture is projected which will induce patrons to come again, it is of no importance to consider reduction in cost. The whole question, therefore, is reduced to one of applying the lamp in such a way that the picture meets the public demand for brightness, steadiness, color tone and sharpness of detail.

Three sizes of lamps have thus far been developed for motion picture service. These three lamps are shown in their relative sizes to one-fourth scale in Fig. 1. The 600 watt lamp has a tubular bulb 2.5 inches in diameter with an overall length of ten inches. The 750 watt lamp has a tubular bulb with a spherical portion opposite the filament. The maximum diameter of this spherical portion is 3 5-8 in. and the overall length of the lamp is 11¾ in. The 1200 watt lamp has a bulb which has a maximum diameter opposite the filament of 4.5 in. and the diameter at the top is also 4.5 in. The overall length of this lamp is 13⅛ in. It is of advantage in making lamp-housings for these lamps to have sufficient clearance to take the largest of the three lamps, and then any change in a lamp size may be made by the operator as desired.

The size of the light source, or the projected area of the filament, is nearly the same in the three cases—the area of the light source of the 1200 watt lamp being only slightly larger than the area of the light source used in the 600 and 750 watt lamps. The useful area of the light source can be determined by testing back from the screen on which the picture is to be projected. If a lamp is placed at the corners of the lighted area and a test plate is put in the position of the filament, the spot of light projected back on this test plate will show the useful area of the filament. In all cases it is advisable to make the filament area somewhat greater than is theoretically useful to allow for slight variations in the placing of the filament in the optical system. With the Corning prismatic lens, such as frequently used with the lamps, the theoretical area of the light source is about 11 by 9 millimeters, the larger number being the horizontal dimension of the filament.

With a plano-convex condensing system, the area of the light source is approximately 11 millimeters high by 13 millimeters wide. The projected area of the filament in all cases is about two millimeters greater on each dimension than the useful size which is obtained by back testing. In making the tests for area of light source, the objective lens of the machine should be accurately focused on the screen and the test lamp should be placed close to the screen in order to give a sharp image on the test plate at the light source.

FIG. 1. STANDARD MAZDA C LAMPS FOR MOTION PICTURE PROJECTION

(a) 600 watts, 20 amperes, 30 volts; (b) 750 watts, 30 amperes, 25 volts; (c) 1200 watts, 30 amperes, 40 volts.

In any form of Mazda lamp thus far developed there are spaces between the filament sections which are not sources of light and this has the effect of giving a more or less uneven screen. In order to eliminate this effect a spherical mirror is usually mounted behind the light source, and the source is adjusted until the reflected image from the mirror falls between the sections of the coils. In this way a part of the light which would otherwise be wasted is returned to the condenser and the distribution of light over the surface of the screen is made more uniform. Where the filament is

arranged in a single row, which is known as the monoplane construction, the images of the coils from the mirror are projected partly between these coils and partly on the coils themselves. Where the filament is arranged in two rows with the coils in the second row behind the spaces betwen the coils in the first row, the reflected image comes back more or less on the coils,

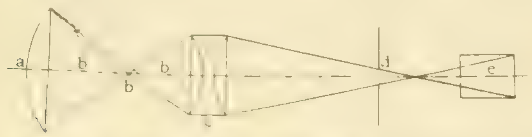

FIG. 2—DIAGRAM SHOWING NECESSITY FOR ACCURATELY FOCUSING THE LAMP AND MIRROR

a—mirror; *b*—light source; *c*—condensers; *d*—aperture plate and *e*—objective.

but in each case there is an improvement in the uniformity of the light. The mirror must be accurately placed in order that the best results may be obtained. The reflected image of the coil should be equal in size to the coil itself and come practically into the same plane as the coil. If these conditions are not fulfilled and if the mirror is badly out of focus, the reflected coil image may come either on the bulb or so near to it that it will cause the glass to soften and result in early failure of the lamp. There is, in fact, only one point in the optical system which is the correct point for the lamp filament. This is represented in Fig. 2 where *a* is the mirror; *b* is the light source; *c* the condensers; *d* the aperture plate and *e* the objective. If the light source is ahead of the true position; that is, at b', the image of the light source will be formed at b'', the image coming nearly the same distance to one side of the correct point as the filament is placed on the opposite side of this point. Since this condition exists and, as in practically all apparatus which is on the market at the

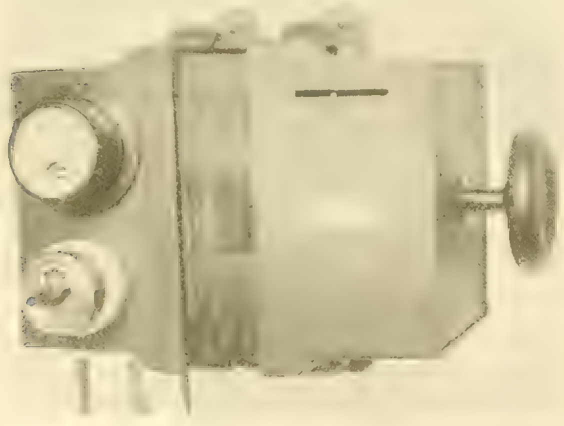

FIG. 3—TYPICAL TRANSFORMER FOR PROJECTION SERVICE

With ammeter, three-point switch and reactance control.

present time, the mirror is moveable, the chances of getting the filament in the right position are rather remote.

It is helpful, in focusing the light source, to project the filament and its reflected image on the screen or on the blade of the shutter of the projector. By careful manipulation the size of the filament image and the size of the reflection image may be made nearly equal and good results obtained. When a lamp is to be installed this same focusing process must be repeated.

The focusing of Mazda lamps in the manner outlined follows the established practice in focusing arcs which are continually changing their position and, therefore, require continual manipulation. It is perfectly feasible, however, to adjust the filament of a Mazda lamp to a predetermined position with respect to a lamp holder and have this lamp holder fit into the lamp-house in such a way that the filament of any lamp may be brought exactly to the proper focal point. Apparatus of this kind is not only more simple and more rugged in construction, but results can be duplicated much better than where unnecessary adjustments are permitted in position of mirrors, light source and condensers. The position of the mirror with respect to condensers should be fixed, and all adjustments should be made on the

FIG. 4—TRANSFORMER ARRANGED TO OPERATE TWO LAMPS ALTERNATELY

Provided with ammeter, pilot lamps, switch and regulator.

light source itself. In general fully as much, if not more, skill is required in adjusting the light source where a Mazda lamp is used as where an arc is used, the only difference being that with a Mazda lamp, if the set-up is correctly made, it will remain unchanged during the life of the lamp, while with the arc this skill must be exercised continuously.

Where Mazda lamps are used on alternating-current circuits, it is advisable to use a three-wing shutter on the projection machine rather than a two-wing, which is essential with an alternating-current arc. The change to the three-wing shutter may be made because of the fact that the light source does not change appreciably in intensity during the current cycle. The filament stores up so much heat that it does not have time to cool off during the time the current is passing through its zero value. With an arc, the luminosity varies in a definite relation to the instantaneous value of the current. The use of a three-wing shutter is an advantage because it permits the frequency of cut-off of the pic-

ture to be high enough to eliminate the sensation of flicker. The transmission of light through a three-wing shutter is somewhat less than through a two-wing shutter, and the ideal combination is, therefore, to use a light source sufficiently powerful to permit a three-wing shutter to be used and at the same time secure a brilliant picture on the screen.

Owing to the limited light flux from the filament of a Mazda lamp, and the use of condensers which cause greater convergence of the light rays, it is frequently desirable to use an objective of large diameter. There are at the present time on the market lenses having diameters of 2.5 in., and these lenses are to be recommended where the throw is long, in order that there may be as little waste of light as possible. With the use of a wide aperture lens, careful adjustment of the shutter is essential to prevent the appearance of travel ghost; that is, the stringing out of the letters of titles at the top or bottom, or both, thus giving the effect of an indistinct picture. Unless special care is taken to set the shutter correctly, satisfactory projection will be impossible where a wide aperture lens is used.

The Mazda lamp is rated at extremely high efficiency and therefore the current supplied to it must be accurately controlled if the lamp is to give satisfactory life performance and at the same time satisfactory illumination of the screen. Lamps made up at different times may vary somewhat in current rating and, therefore, hand regulation must be provided on the current controller. For alternating-current circuits a small transformer is used. There are a number of these transformers now on the market. The transformer is provided with an ammeter in the secondary circuit to indicate the current supplied to the lamp. Adjustment is provided by means of a rheostat or reactance, or by a dial switch making connection to different taps on the winding in order to control the current when the voltage supplied to the transformer varies. Typical transformers for this service are shown in Figs. 3 and 4. The regulation in the transformer shown in Fig. 3 is accomplished by means of an adjustable shunt in the magnetic circuit. The transformer shown in Fig. 4 provides regulation by means of a dial switch which makes connection to different taps on the winding. Five leads are brought out, one pair being for the primary circuit and the other three being for connection to the lamps in two lamp-houses.

The principal features involved in the application of the new Mazda lamp for motion picture projection are outlined in the foregoing. The future of this business depends very largely upon the successful development of thoroughly reliable and inexpensive auxiliary devices such as the lamp-house mechanism and the electrical control devices. The Mazda lamp is especially suited to the smaller theatres where the investment in equipment is necessarily limited. At the same time it is of extreme importance that the auxiliary equipment be rugged and not easily put out of order, because it is essential that the performance, when once started, be continued without interruption.

Lightning Protection for Special Transmission Lines

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This article discusses the application of lightning protection apparatus, and especially of electrolytic lightning arresters, to transmission lines which are somewhat out of the ordinary. (Ed.)

Within the last few years there has been considerable increase in the number of three-phase four-wire distributing lines and low-voltage transmission lines. This has been due to the increased loads and to the inability to increase the load capacity of a given line by connecting the transformers in star and operating the line at a higher voltage. On such lines it is the usual practice to connect the single-phase branch feeders between the neutral or fourth wire and one of the other three lines. This introduces lightning arrester conditions of more than passing interest. Unless the effect of the neutral wire is understood, the arresters are liable to be installed in such a manner that they will not be suited to all the conditions of the system.

The first condition is that of a line in which the neutral is not grounded. Fig. 1 shows schematically an electrolytic lightning arrester adapted to the protection of a three-phase four-wire line. The only special feature introduced is the bringing out of a fifth lead from the neutral point of the arrester and connecting it to the fourth line wire through a plain horn gap. This fourth gap does not require a charging resistance, and does not require a charging device or short-circuiting clip, as this requirement is provided for by the other three gaps. If it were not for the possibility of a ground on the line and consequent continuous passage of current through the fourth element of the arrester, the fourth gap might be omitted and the fourth wire connected directly to the neutral point of the arrester.

Another condition, encountered on a three-phase four-wire system, differs from that in Fig. 1 in the introduction of a grounding resistance and a grounding switch in the neutral lead. The safe arrangement of arresters is shown in Fig. 2. The fourth electrolytic

element in Fig. 2 can be omitted if the following conditions are obtained:—

a—The ohmic value of the grounding resistance must be sufficiently low so that the circuit breaker will trip out when a ground occurs on the line. The three-element arrester will give the same degree of protection, whenever the above condition obtains and it costs somewhat less.

TYPICAL LIGHTNING DISCHARGE

Over the Gulf of Genoa. Taken from the works of the Italian Westinghouse Company at Vado, Ligure.

There must be assurance that the grounding switch will not be opened. If a system is being operated with a grounded neutral and the neutral is grounded through a switch, the system would probably be operated that way, until a ground occured on the line. When the ground occurs, the circuit breakers disconnect the affected line and the service is discontinued. To restore the line to service one of two things must be done:— 1—Send out linemen to locate and remove the ground. This may require only a very short time or it may require several hours. 2—Open the grounding switch and resume operation at once with one line grounded. But if at the same time the operator forgot to disconnect the arrester, and the gaps were set too close, or a lightning discharge came in on that line, 100 percent line voltage would be placed across an electrolytic element which is designed for only the 58 percent of the line voltage. This would very likely result in serious damage to the arrester if not its destruction, unless there are fuses which will automatically disconnect the arrester.

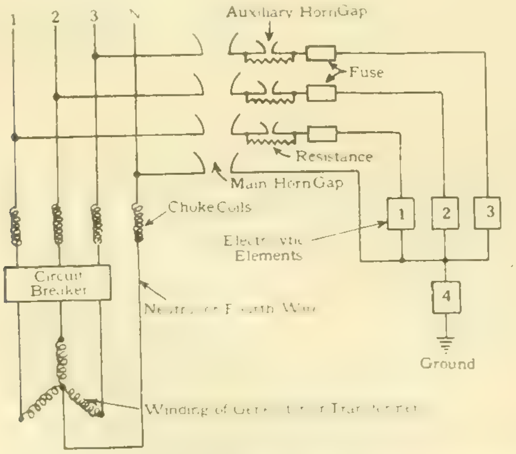


FIG. 1—CONNECTIONS OF A THREE PHASE, FOUR WIRE SYSTEM

With neutral wire ungrounded.

This condition brings out one point in favor of the use of fuses on electrolytic lightning arresters. The arguments against the fuse are:—the space taken up by the fuse and the loss of protection until a blown fuse is replaced. Both of these arguments are true to some extent, but there are ameliorating conditions. With indoor installations the space consideration is of some importance, but on outdoor installations where space is no consideration this argument is of very much decreased importance if not entirely eliminated. The fuses furnished on electrolytic arresters are usually sufficiently heavy so that they will only burn out under the most severe conditions; viz. with a lightning discharge sufficiently heavy to destroy the arrester or in cases where the film has become so low that the arrester can not check the flow of dynamic current. In such cases, the fuse burns out and it is only necessary to replace it,

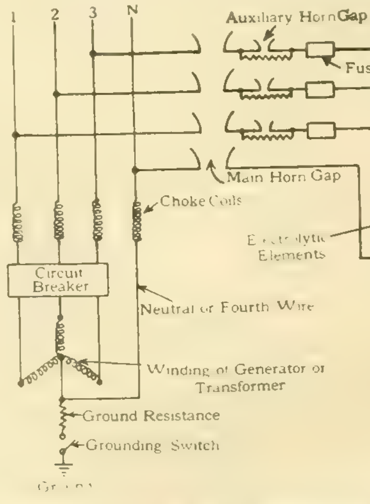


FIG. 2—CONNECTIONS FOR THE PROTECTION OF A THREE-PHASE, FOUR-WIRE SYSTEM

With the neutral grounded through a resistance.

which takes but a few moments, and then in case of the low film impress a voltage of about 220 volts across each cell through a lamp bank, to build up the film. If the fuse is not present to take care of these cases there is the possibility of serious damage or destruction of the arrester and necessity of rebuilding the arrester and in many cases waiting for repairs to be supplied from the factory, which would leave the arrester out of ser-

vice and the line unprotected for a much greater length of time than is required to replace a fuse.

The electrolytic lightning arresters for two-phase four-wire are similar to those for three-phase three-wire except for the addition of a fourth horn gap and three-phase systems.

Electrolytic lightning arresters are also listed for two-phase, three-wire systems of low voltage. These systems are very rare —the writer knows of only two systems in this country. The insulation of these ar-

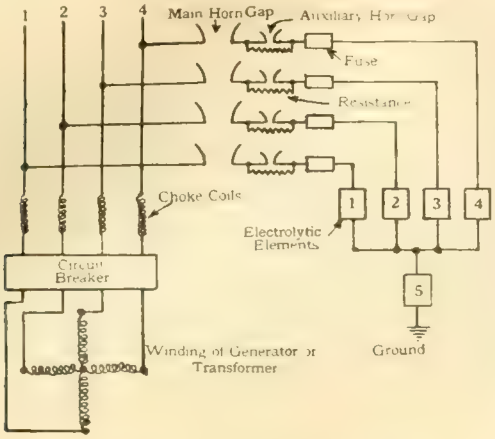


FIG. 3—CONNECTIONS OF A TWO-PHASE, FOUR-WIRE SYSTEM

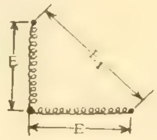


FIG 4—VOLTAGE RELATIONS IN THE GENERATOR WINDINGS OF FIG 5

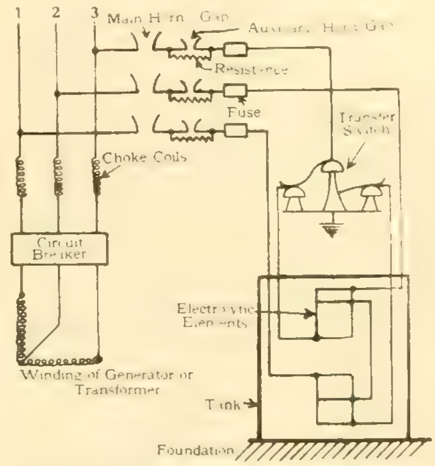


FIG. 5 CONNECTIONS OF A TWO-PHASE, THREE-WIRE SYSTEM

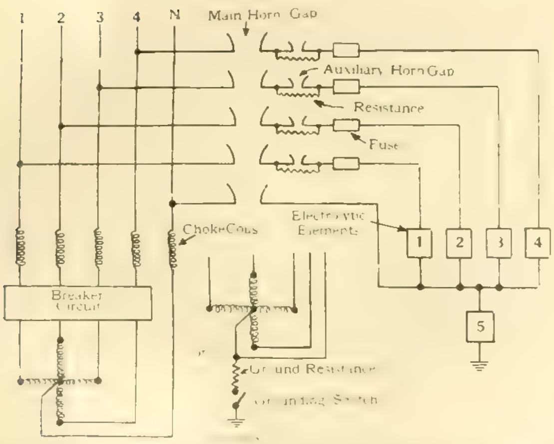


FIG. 6—CONNECTIONS FOR A TWO-PHASE, FIVE-WIRE SYSTEM
Using five electrolytic lightning arresters.

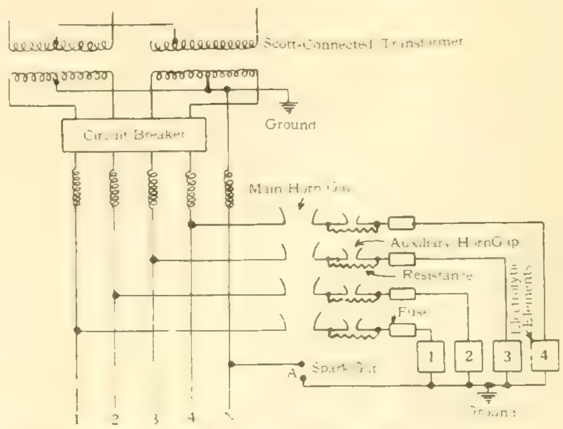


FIG. 7—CONNECTIONS OF A TWO-PHASE, FIVE WIRE SYSTEM
With neutral grounded.

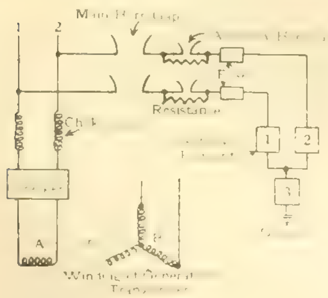


FIG 8—CONNECTIONS OF A SINGLE-PHASE SYSTEM

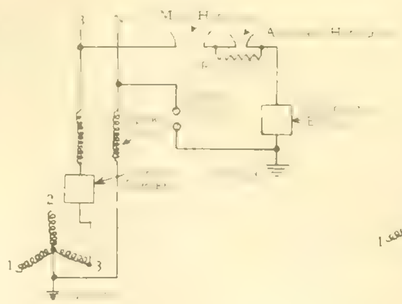


FIG. 9—CONNECTIONS OF A SINGLE-PHASE SYSTEM
With one side grounded.

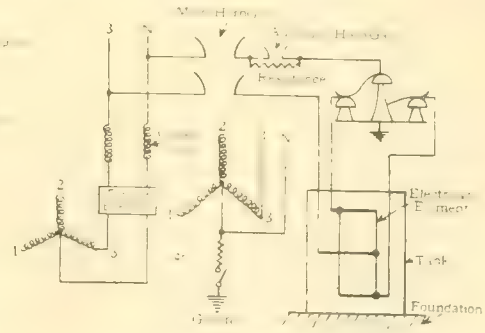


FIG. 10—CONNECTIONS OF A SINGLE-PHASE UNGROUNDED SYSTEM

a fifth electrolytic element. A transfer switch is always provided for interchanging the grounded electrolytic element with one of the electrolytic elements connected to the line. There are not many of these systems in existence. Most of the two-phase systems are survivals of the early electrical developments, where it has not yet been found expedient to change them to

resters must be considerably higher than that necessary for a three-phase or two-phase arrester of the same voltage rating. The reason for this is shown in Fig. 4, in which E is the rating of the system while E_1 is the maximum voltage between any two lines. The tray arrangement is similar to that of the three-phase arrester except that three of the elements must have sufficient

trays for voltage, $0.5E_1$, while the fourth element must have sufficient trays for voltage E - $0.5E_1$, and this fourth element must be connected to the common wire of the two-phase and the transfer switch.

A combination of gaps and electrolytic elements suited for a two-phase, five-wire ungrounded neutral is that shown in Fig. 6 which has exactly the same considerations as given under the three-phase systems. The scheme differs from that in Figs. 1 and 2 in the addition of an extra main transmission wire to which is connected an extra set of gaps and electrolytic element, the same as for line 1, 2 and 3.

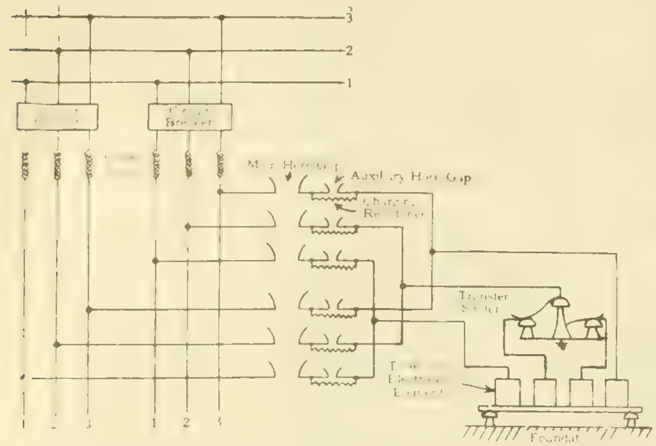


FIG. 11—SCHEME OF PROTECTING TWO, THREE-PHASE LINES WITH ONE SET OF ELECTROLYTIC ARRESTERS

Another combination which is sometimes encountered is that shown in Fig. 7. The choke coil in lead N may not be thought to be necessary but it is a step toward a greater degree of safety, as lightning has in many cases been known to pass by a ground which was prepared for it and punctured the windings of the apparatus. Outside of this coil should be placed a small spark gap as shown at A.

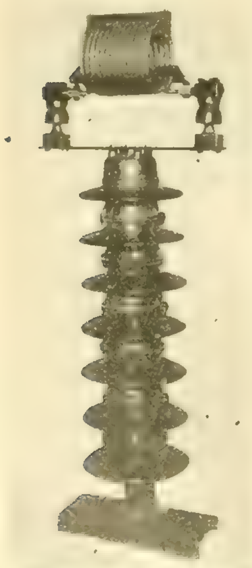


FIG. 12—[illegible] OUTDOOR TYPE CHOKE COIL

The connections of the ordinary single-phase lightning arrester are shown in Fig. 8. In combination A, Fig. 8, each element must have sufficient trays for 50 percent of the line voltage while in combination B the number of trays must be sufficient for 58 percent of the line voltage. The ordinary single-phase lightning arrester is supplied with sufficient trays to meet the requirements of combination B.

When single-phase lightning arresters are connected to a single-phase feeder line which is connected between the neutral wire and one of the outside wires of a three-phase or two-phase system, special considerations are introduced. If the neutral is solidly grounded then only one horn gap and electrolytic element need be placed in series between the other line and ground. The arrangement is shown in Fig. 9. If a single-phase system of this character is operated with the neutral ungrounded or if it is connected to ground through a high resistance or if there is a possibility of its being operated with the grounding switch open, the arrester should be arranged as shown in Fig. 10. The same conditions obtain if a two-phase, five-wire system is used instead of the three-phase, four-wire system shown in Figs. 9 and 10.

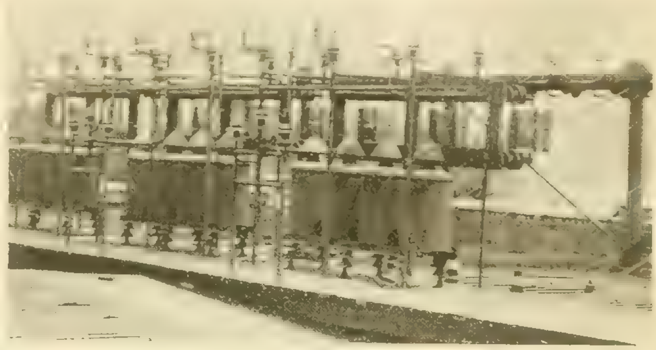


FIG. 13—TYPICAL INSTALLATION OF ELECTROLYTIC LIGHTNING ARRESTERS, HORN GAPS AND CHOKE COILS

A frequently occurring proposition is that of protecting two or three lines by one arrester by using additional horn gaps. This can be done, provided the lines are of the same potential and have the same phase relation such as would be obtained if the lines were connected to a common bus as shown in Fig. 11. The other main consideration is the ability of the arrester to handle the discharge of two or three lines. In regions when electrical storms are not severe it can be done and it can also be done when the storms are moderate, provided the tray area is large, but in cases where the storms are very severe and especially where the tray area is small, such an arrangement is not to be recommended.

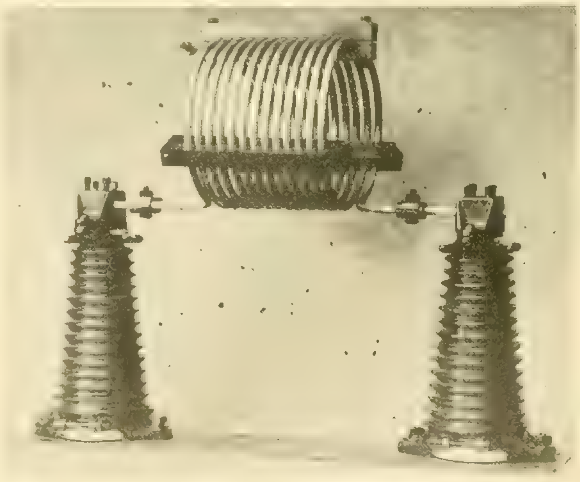


FIG. 14—33 000 VOLT, 200 AMPERE, INDOOR TYPE CHOKE COIL

Milestones in Small Turbine Development

Ivan Stewart Forde
Manager, Small Turbine Division
Westinghouse Electric & Mfg. Co.

IN THE COURSE of a recent address, one of our eminent engineers made the following remarks bearing on progress both in machinery and along engineering lines:—

"If you wish to progress, get over the habit of being old fashioned in your life and work. Because something was good twenty years ago, do not take it for granted that there is nothing better today. Investigate new things, new ideas, new machinery; discuss these improvements with your employers and associates, for without discussing and encouraging these advancements, progress cannot be made. Even the things of yesterday may be obsolete, with improvements over night—hence the necessity of your knowing the changes of today and anticipating the betterments of tomorrow."

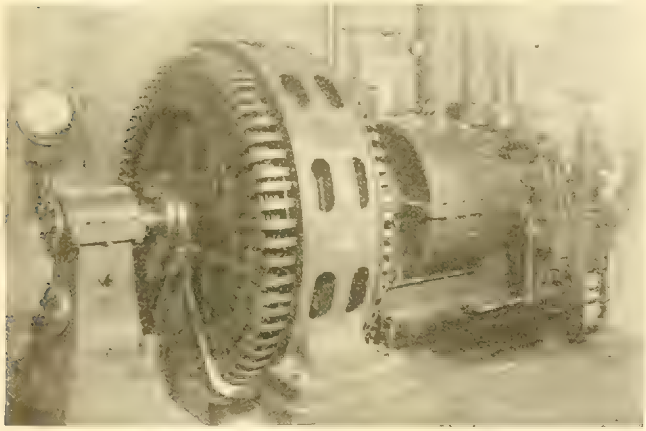


FIG. 1—750 KW. ALTERNATING CURRENT GENERATOR GEARED TO A NON-CONDENSING TURBINE

The turbine operates at a speed of 6000 r.p.m. and the generator at 900 r.p.m. This unit is installed in what is known as a steam sub-station of a large central station which furnishes heat, light and power to a manufacturing plant and generates only sufficient energy to supply the necessary exhaust steam, the generator being tied in electrically with the main generating station.

How true this is of small turbines, when one considers the progress made in the past several years. Would you have considered them as a source of power twenty years ago; or five years ago, would you have felt the need of a 500 or 750 horse-power turbine for driving boiler feed pumps? Would you also have made inquiry of a turbine builder for a 750 or 1000 kilowatt direct-current generating unit as auxiliary power in a large central station? All these things today are milestones in the development of the sometimes "belittled" small turbine.

Until recent years, the growth in small turbine production, while representing a healthy increase, did not indicate the spectacular demand so noticeable during the past three or four years. One immediately says: "That doesn't signify anything—all machinery builders are working overtime." But consider, if you will, that there are perhaps four times as many engine builders to compete with the production of a dozen steam turbine factories; whereas if a manufacturer decides to install electricity in his plant, he must buy a generator or motor of one or another manufacture.

The present-day growth of the small turbine is spectacular. There are now a dozen manufacturers turning them out with total annual sales aggregating roughly $16 000 000, whereas five years ago this field was limited to a baker's half-dozen with total sales of approximately $4 000 000. What, then, has caused this growth? It is true that a small turbine is more compact than reciprocating apparatus, lighter in weight, requires less foundation and, in addition, is less expensive in first cost, freight and erection. But is that all? Would you purchase any apparatus on first cost alone? The real reason small turbines are popular is because they are simple in construction, require very little attention, lubrication and adjustments; and also because they are able to operate for long periods without shutdown.

FIG. 2—GENERATING STATION OF THE EMPIRE DISTRICT ELECTRIC COMPANY OF JOPLIN, MO.

Having 250 horse-power steam turbines operating at 3600 r.p.m., which drive boiler feed pumps at 1800 r.p.m., through reduction gears.

And yet, the small turbine was not developed solely for the purpose of having something to compete with another source of power—the steam engine. It became a necessity with the development of large turbines—their condensers with centrifugal hot well, vacuum and circulating pumps, boiler feed pumps, blowers and kindred auxiliaries about big stations, which could no longer be driven by reciprocating apparatus when capacities, speeds and space requirements dictated a change. It is true that the small turbine has effected lower first costs in power house auxiliaries, but it is equally true that their performance has been more remarkable. Small turbines have operated for a year or more at a time without shutdown. They are started up and, you might say, "forgotten." This is not cited to indicate how small turbines should be operated, but as an example of how they sometimes perform even with lack of attention. Even though the turbine possesses

certain inherent characteristics, enabling it to operate continuously for long periods, it is advisable and recommended that periodic inspection be made of the auxiliary apparatus in much the same manner as any other apparatus, reciprocating or centrifugal.

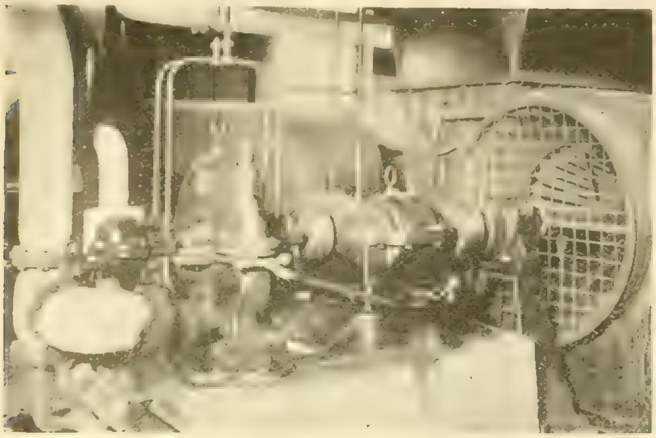


FIG. 3—AN 80 HORSE-POWER STEAM TURBINE

Operating at a speed of 5400 r.p.m., and driving a stoker draft fan at a speed of 1150 r.p.m. Had this combination been direct connected instead of geared, it would have cost more than the geared unit and its steam consumption would have been 60 pounds of steam per brake horse-power hour instead of the 35 pounds which it now requires.

Ten years ago, a prominent builder of large turbines entered the small turbine field with the primary object of using them to drive their own condenser pumps, later using these same turbines for driving centrifugal pumps and other mechanical apparatus generally. Following this small direct-connected generator units were brought out, and later small turbines on a large scale for other commercial work, and this small turbine enterprise gradually increased until it is now an important factor in their total production of steam apparatus.

In the early stages of the small turbine development, moderately high speeds were employed for both the

FI[illegible] THE UNION DEPOT TERMINAL FOR THE [illegible] DALLAS, TEXAS

Two of these units have a capacity of 250 k.v.a. and the third unit 312 k.v.a. The turbines are of the noncondensing high-speed design and are geared to slow-speed generators which furnish heat, light and power to the terminal.

driving and driven apparatus—pumps, blowers and generators—the obvious reason being that, since the turbine improved in economy with increased speed, the driven apparatus was accordingly increased in speed for direct connection to the turbine—reduction gears not being seriously considered at that time. Just imagine a turbine builder seven or eight years ago offering a 100 or 750 kilowatt geared generating unit with turbine speeds of 7200 and 6000 r.p.m. Would you have bought it then? Today such a geared unit is accepted very much as any other standard article—unquestioned. It is more compact than a direct-connected combination, more economical by at least ten pounds per kw-hr., its cost is no greater and the buyer obtains better driven apparatus by virtue of slower speeds.

The small turbine, as originally built, was for auxiliary purposes only, and the user paid very little attention to its steam consumption, provided the consumption of steam was within certain definite limits which the purchaser had in mind when he bought it. Times have changed. The same purchaser today will immediately ask the builder what is the water rate of his turbine? This is because coal is scarce, costs considerably more than it did and because the plant operator has worked out the heat balance in his plant to such a fine point that

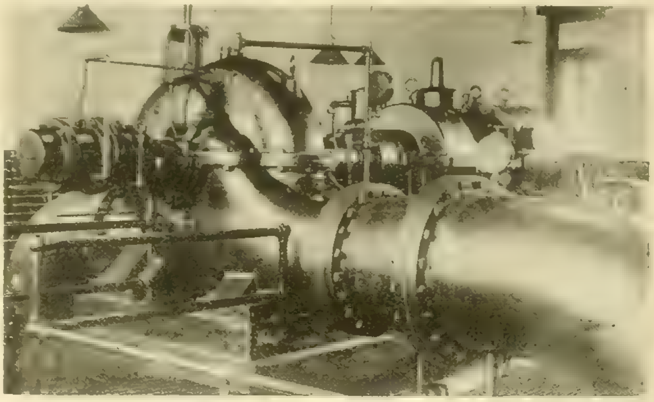


FIG. 5—750 HP STEAM TURBINE

Operating at 6000 r.p.m., and driving a centrifugal pump handling 10 400 gallons of water per minute. This turbine is designed for high steam pressure and high vacuum, and the pump, which is designed for a relatively high head, has a speed of 1400 r.p.m.

he does not care to have "waste" exhaust steam. This same question of economy has become even more pronounced in connection with small turbines driving direct-current generators for use as exciters and auxiliaries about the station.

It is interesting to note the ever-changing requirements of small turbine-driven boiler feed pumps, stoker draft fans, condenser pumps and exciters. For boiler feed pumps, the horse-power demands will vary anywhere from 15 or 20 horse-power for a 1000 boiler horse-power plant up to an occasional inquiry for a unit requiring 500 or 600 horse-power, capable of handling 45 000 boiler horse-power or approximately 90 000 kilowatts. The speeds of these pumps vary materially with different manufacturers, and for a 50 horse-power turbine-driven pump, one manufacturer may call for a speed of 2400 and another manufacturer 3000 or 3600 r.p.m. for the same work. Depending upon the capacity of the pump, the speeds will vary anywhere from 1500 to 3600 r.p.m. Just a short time ago, one turbine builder had occasion to check up the horse-powers and

speeds of small turbines for this work, and learned that of 400 turbines built the average was 70 horse-power and the speed 2500 r.p.m.

Turbine-driven stoker fans have an entirely different set of operating conditions. They start off with 40 horse-power and a speed of 2350 r.p.m. (capable of handling 1600 boiler horse-power) and increase to 250 horse-power and decrease in speed to 800 r.p.m. for an installation of 10 000 boiler horse-power.

Turbine-driven circulating pumps for surface condensers have still another requirement. While the capacity will vary from 1000 to 60 000 gallons per minute, they are always designed for low heads and consequently low speeds. It is seldom that a circulating pump for low head surface condenser work exceeds 1000 r.p.m. in small capacities. As this is increased up to 25 000 gallons per minute, the speed is decreased to about 500 r.p.m. and, as the condition of 60 000 gallons per minute is reached, the speed is still further reduced to as low as 300 r.p.m.

Direct-current generating units as auxiliaries in large power houses are of equal interest, and the turbine builder is called upon to supply exciter units of

FIG. 6—500 KW SLOW SPEED GENERATOR GEARED TO A CONDENSING TYPE TURBINE

not only 10 and 15 kilowatts capacity, but up to one thousand kilowatts. When these large capacities are reached (certainly greater than the excitation current required on large alternating-current generators), it would indicate the use of direct-current motors for special operations in or near the plant, such as driving coal and ash handling machinery, and possibly the furnishing of direct-current light and power to nearby users.

All of the small turbines, as originally built (with the exception of those of one manufacturer), were direct connected, because reduction gears were neither considered nor developed for small requirements. There are, however, many good reasons why the small turbine of today should be geared, these advantages holding good both from the standpoint of builder and user. With *direct-connected* small turbines, a builder must have one group of small turbines with variable speeds for driving all centrifugal pumps and fans and the variation in speed is quite large. Then there must be 3600 r.p.m. turbines for driving alternating-current generators, and lesser speed turbines for driving direct-current generators.

It is admitted that the economy of a small turbine materially improves with increased speeds. It is also true that the speed of a centrifugal pump depends upon its hydraulic conditions of operation, and that it never attains the *economical* speed of a turbine without some sacrifice. This is not so noticeable in the case of the high-head, high-speed boiler feed pumps as in the case of the low-head, low-speed circulating pumps on large condensers. It was a question of "give and take" between the turbine builder and pump manufacturer, with a sacrifice in most cases by both of them. Today all the pump manufacturer has to do is to tell the turbine builder what speed he considers best for the *pump*, and he will be given a turbine and gear arranged so that the efficiency of the turbine and the efficiency of the pump will make an overall combination never attained by the direct-connected unit. This, too, with relatively little increase in cost. This enables the turbine manufacturer to concentrate on a smaller number of turbine frames, thus not only making them better but relatively cheaper due to increased production. The same holds good with reference to turbine-driven blowers, which are daily becoming a greater factor in the demand for small turbines, due to the increased use of underfeed stokers.

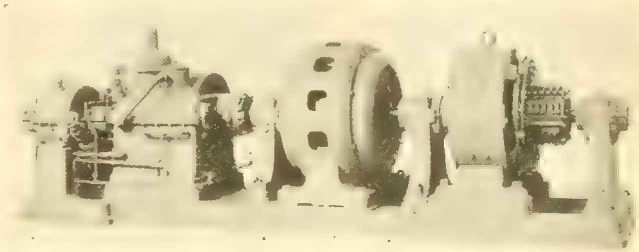


FIG. 7—300 KW STEAM-ELECTRIC EXCITER SET

The generator can be operated either from the geared turbine or the alternating-current motor or both. The usual method is to drive the set by the electric motor, the steam end running idle and then coming into operation either with the slowing down of the motor or with a demand for exhaust steam from the turbine. With the ever increasing demands for economy of exciter sets, this geared steam-electric combination consumes less steam than a direct-connected combination of the same type.

Then there is the electric generator. By the use of a reduction gear use can always be made of standard, moderate-speed electric generators both alternating and direct-current, with better efficiency, due to decreased friction and windage, and admittedly better commutator construction on the direct-current generator due to slower speeds.

The power-house operator has gained by this elimination of so many different types, first by getting apparatus on which he can standardize, and second, by obtaining economies on his auxiliaries which will let him work out to a nicety the heat balance in his plant.

The rapid increase in popularity of the small turbine is evidenced not only by the increased sales of small turbine-driven auxiliaries in large power-houses, but by the installation of small turbine-driven generating units to serve as the main units in small manufacturing plants, where use is made not only of the electric energy, but the exhaust steam is used industrially in

manufacturing processes of one kind or another. The demand from such plants has never been as great as it is today.

Small turbines have also become quite popular as the main generating units in central stations of small and moderate capacities requiring 200 kilowatts and upwards, alternating-current, operating the turbine with a simple jet condenser having motor-driven pumps. In this way the combined water rate per kw-hr. of the turbine and condenser is quite low since the auxiliary power is taken from the main unit at its economical rate of consumption. In this case the only exhaust steam about the plant is that used in the small reciprocating boiler feed pump, which is usually sufficient for supplying heat to the incoming feed water.

Still another field is opening up in the use of geared turbines for driving not only other mechanical apparatus, such as variable speed paper mill machines, the main shaft in flour mill drives and water works pumps, but for marine propulsion as well, this latter field becoming very large since the war.

Possibly a word or two about the difference in the efficiency between geared and direct-connected units would be of interest. In the case of one turbine builder, they were able to reduce by 10 pounds of steam per kw-hr. the steam consumption of small generating units in changing over from direct-connected to the geared type of unit. In the case of a 25 hp turbine driving a pump at 1500 r.p.m., they were able tc reduce the steam consumption from 60 pounds to 37 pounds per brake hp-hr. In the case of a 100 hp turbine driving a pump at 2500 r.p.m. a saving of 18 pounds per brake hp was effected. It will be noted that these savings are so great that they cannot be overlooked by operating men who have the economy of their plants at heart. Probably no greater evidence of this can be found than in the fact that at least one turbine manufacturer is today building geared units in the ratio of ten to one direct-connected unit.

The Selection of Demand Meters

C. A. Boddie

The tendency in recent discussions on the subject of demand metering has been to regard it as rapidly approaching an art in which the problem can be stated in exact terms and for which an exact solution should be forthcoming. The development of such devices, however, has been under the continuous handicap of the variables inherent in the problem.

The principal factor which limits the load which the equipment of a system can carry is temperature, and therefore demand measurement is closely related to the limiting temperature of such equipment. This equipment having mass, requires an appreciable time to reach a final temperature for any given load. This temperature results from losses incident to the load. In a generator, for example, the armature losses vary in proportion to the square of the current and the field losses vary with power-factor of the load as well as the current. In a transformer, the core losses are substantially constant while the copper loss varies as the square of the current. In a cable the losses vary as the square of the current. It will be seen, therefore, that the heating of the system equipment follows a law not susceptible of simple expression.

The demand meter must recognize, directly or indirectly, these two factors, temperature and time. Demand meters differ mainly in their recognition of time.

It has been considered logical for such meters to be designed so that they will follow the actual heat storage law of system equipment. As pointed out, however, where various classes of system equipment are under consideration, the law becomes complicated and other conditions enter also into the measurement of demand entirely beyond the recognition of the meter, for example, diversity factor, power-factor, voltage regulation, etc. It is impossible for any practical device to take into account all of these conditions, and the demand rate is, therefore, generally altered by a number of arbitrary factors intended to compensate for these variables, and the result is an obvious compromise when referred to the actual heat storage. The compromise is of such degree that the exact time law of the meter becomes of secondary importance so long as the meter fulfills the practical requirements. These requirements may be expressed as follows:—

1—Its law should be such that it will evaluate any fluctuating load in terms of an equivalent steady load.

2—Its law should be readily interpreted, and its readings readily susceptible of simple mathematical verification, so that the consumer may understand the meter and have confidence in it.

3—Its indications should be reliable, that is, the meter should remain in calibration.

4—Its indications should constitute an acceptable fulfilment of the contract for which it is the standard of measurement. This implies that contracts should always be drawn up with due regard to the state of the demand meter art.

The progress of the art to date has developed two distinct types of devices:—the arithmetical average or block interval type, and the time lag or delayed indication type. Each has its field of application dependent upon local conditions of operation and contracts.

Owing to the simplicity of calculation, the arithmetical method of averaging instantaneous values of load over a specified interval has become the standard of reference, and the block interval meter which involves the same principle is, therefore, generally used for large power installations.

Simplicity of operation and maintenance on the other hand make the lag type meter particularly applicable for small power installations.

Feeder Voltage Regulators

For Outdoor Operation

I. C. Minick

AMONG the various problems which war conditions have thrust upon many central station operators is that of handling increased loads without adequate increase in the transmission or distribution lines. In some systems, the distribution of the load has changed so rapidly that certain feeders have become disproportionately loaded. In many cases it has been found also that the location of the load center on the different feeders has been completely changed by the increased power demand. Such conditions interfere with the voltage regulation on the individual feeders and, unless corrective measures are taken, will result in poor lighting, lamp burnouts and decreased efficiency of motors.

A voltage chart showing the conditions which are at times produced by an electric furnace load is shown in Fig. 1. Where the voltage fluctuations are not too rapid, a regulator will smooth out the variations of the entire circuit. In some cases, however, the voltage variations occur within a fraction of a second, so that it is impossible for an induction type regulator to follow them. Under such circumstances the proper procedure is to separate the lighting from the power load by means of a branch circuit, and put an induction regulator on the branch circuit.

With the view of remedying so far as possible the fore-going conditions as well as providing a type of

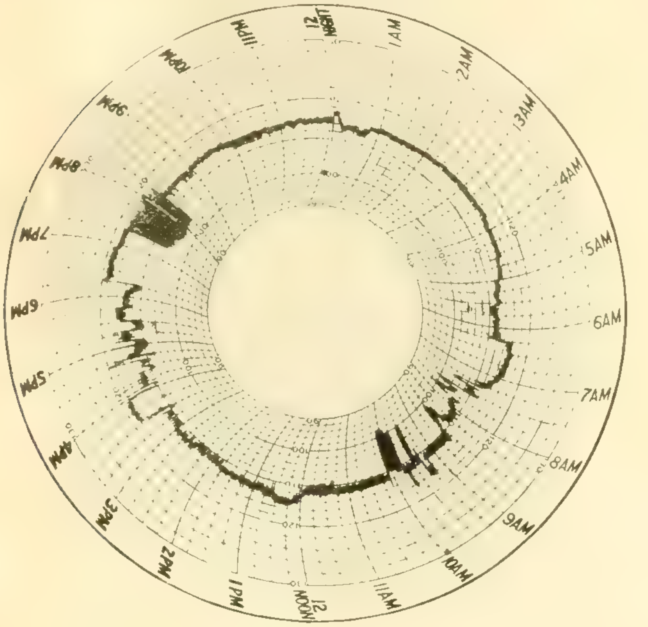
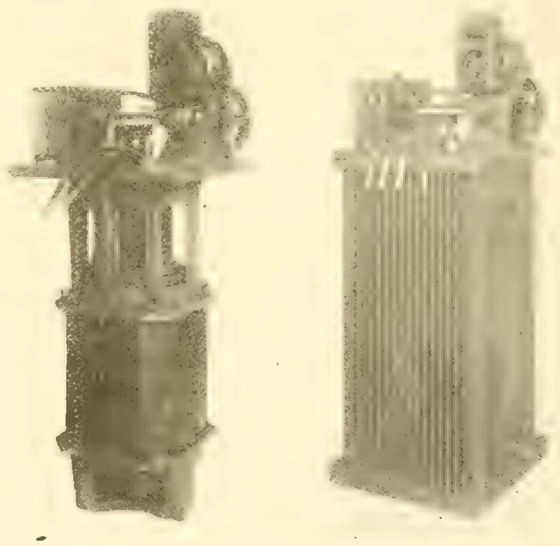


FIG. 1 TYPICAL VOLTAGE CURVE

On a long feeder supplying an electric furnace load.



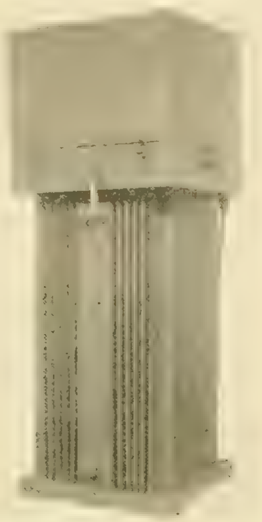
FIGS. 2 and 3 STANDARD SINGLE-PHASE, 60 CYCLE, 2300 VOLT INDUCTION REGULATOR

For ten percent regulation above and below the supply voltage.

The same difficulties have arisen where factories for producing war materials have been located at some distance from the larger cities and require relatively large blocks of power to be supplied by the central station company over hastily constructed lines. In few instances has it been practicable to erect a permanent substation equipped with all of the necessary regulating and controlling apparatus to maintain a steady voltage. Outdoor substations, consisting of a bank of transformers, with the accompanying switching and protective equipment, are usually installed, and all power for both the motor load and lighting is taken directly from the transformers. The lighting service is thus affected in some degree by the variations of the power load. Where electric furnaces or electric welding and heating processes are carried, the effect on the voltage is likely to be so serious as to render the lighting unsatisfactory.

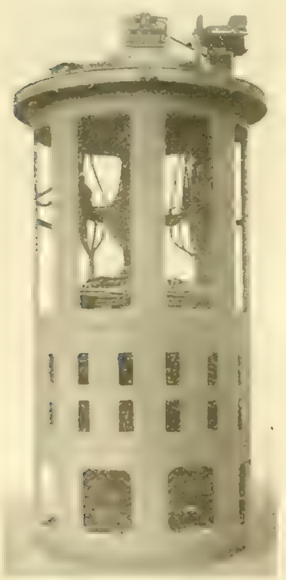
feeder regulator suitable for all classes of outdoor substations, developments were carried out on the induction type regulator which has been in successful use in indoor service for a number of years. In carrying out this development, it was the aim to use only standard parts which had been thoroughly proven in service and which would in no way be affected by outdoor operation if suitably protected. Also considerable attention was paid to the matter of relays and the other accessories for automatic operation; only those types being used which experience had shown would operate for reasonable periods of time without attention. The complete design as finally worked out consisted of a standard indoor type regulator, mounted in a sheet steel "cast-in" tank, and completely enclosing the top cover by a rectangular shaped sheet steel housing, the top half of which can be raised on a hinged joint, as shown in Figs. 4 and 5.

The sheet steel housing is made with a flange about four inches in width extending around the four sides of the lower half of the housing at approximately three inches from the lower edge. The flange rests on a felt gasket which is placed on the top casting of the regulator tank wall. With this construction the completely assembled regulator with all accessories, which are mounted on the top cover, may be lifted as a unit from the tank without disturbing the housing. To remove the regulator from the tank, the leads which are brought out of the tank are disconnected and the cap bolts which clamp the regulator top cover to the top casting of the tank are removed. This feature is of considerable importance from an operating standpoint as complete inspection or repairs to any part of the regulator may be made, without drawing off the insulating oil, or removing the tank from its location. The felt gasket and flange on the housing form a moisture proof joint when the top cover is bolted down, and further protection is afforded by the overhang formed by the lower edge of the housing. The leads are brought out of the tank through porcelain bushings babbitted in the flange. When closed, the top half of the housing extends down over the bottom half and rests on a shoulder with a felt gasket which extends around the inside of the cover, thus completely sealing the regulator against moisture.



FIGS. 4 and 5—12.5 K.V.A., SINGLE-PHASE, 60 CYCLE, 5000 VOLT, INDUCTION REGULATOR OF THE OUTDOOR TYPE

A regulator of this type is formed by removing the standard regulator from its tank, mounting the outdoor sheet-steel housing over the tank, and replacing the regulator.



[illegible] REGULATOR SHOWN [illegible]

The accessories for providing automatic operation consist of a primary relay, an auxiliary relay and limit switch, resistors for primary relay, and a three-pole, 250 volt knife switch. A voltage transformer is necessary for reducing the line voltage for the primary relay, but is furnished separately and mounted externally (A one k.v.a. distribution transformer is generally used). It is also necessary to provide a low-voltage control circuit for the operating motor, and this circuit must not be taken from the voltage transformer that supplies the primary relay.

FIG. 7—A 600 K.V.A., THREE-PHASE, 60 CYCLE, 13 200 VOLT, OIL-INSULATED, SELF-COOLED INDUCTION REGULATOR FOR OUTDOOR OPERATION

This regulator is arranged for either 10 or 20 percent regulation by connecting the coils in series or in parallel.

In general the outdoor type regulators will be installed near the load to be supplied by the feeder. Where scattered loads must be served, the regulator should be installed at the load center of the feeder. In either case it is the function of the regulator to correct for a variable supply voltage and not to compensate for line drop to a distant point, so that a line drop compensator is ordinarily not required. Provision, however, is made for mounting a compensator along with the other accessories when required. When a polyphase operating motor is used there will be a total of five control wires brought out of the housing in addition to the main leads to the feeder; with a single-phase operating motor there will be four control wires brought out.

The outdoor type regulator may be installed in the same way as a transformer for platform mounting, except that it is essential that the base on which the regulator stands be levelled so as to keep the relays in correct position. Platforms may be erected on the ground, or on poles, or steel towers may be conveniently adapted to carry both the transformers and regulators. Lifting lugs are provided on the sides of the housing, which is of sufficiently rigid construction to permit the lifting of the complete regulator filled with oil.

A hasp on the housing is arranged so that a padlock may be used to safeguard the operating mechanism and relays. Care should be taken in mounting the regulator to allow sufficient head room for opening the top cover for periodic inspection of the relays and operating mechanism. Inspection of the regulator and any adjustment of the relays is greatly facilitated by the arrangement used in this design, the relays being mounted at the front side of the housing while all the leads are taken out of the back of the housing. Opening the cutout switches, completely disconnects all the relays and the operating motor, and the location of the high tension leads avoids all danger to the inspector.

Lighting Economy in War Time

PRESTON S. MILLAR
Chairman, Committee on War Service,
Illuminating Engineering Society

DURING THE PAST WINTER, largely as the outcome of the fuel shortage which proved so embarrassing, artificial lighting as a consumer of coal was the recipient of much attention. Under the stress of necessity which afforded but little time for investigation or even for mature consideration, certain curtailment was undertaken and other curtailment was contemplated. In the midst of the discussion, when the issue was prominently before the public, the Illuminating Engineering Society held a special meeting for the discussion of the subject and the author read a paper on lighting curtailment with a view to placing certain facts before the Society's membership and developing engineering opinion through discussions. This paper was presented before the Society in New York on Feb. 14th and before the Philadelphia Section of the Society on the following evening and was extensively discussed.

These discussions were put forth during the period of embarrassment growing out of the fuel shortage and at a time when the need for saving fuel was prominent in the minds of all as one of the paramount issues. Indications point to another serious coal shortage during the coming winter. The subject of fuel saving through curtailment of artificial lighting must, therefore, commend itself to our patriotic and business senses as one important phase of prudent management or economy, and the views expressed during the recent critical period should prove of value in an advance consideration of the situation which will confront the country next winter.

THE FUNDAMENTAL meaning of the word "economy" is well expressed by the phrase "prudent management." Prudent management of the country's resources is a prerequisite to victory. Among the country's resources artificial light occupies an important place. In order to obtain a perspective, let it be recalled that the country's yearly bill for artifical light is of the order of $500 000 000, which is of the same order as the country's bill for intoxicating liquors and tobacco. Let it be remembered that the total coal employed in the production of electric light is approximately 12 000 000 tons out of a total output of 640 000 000 tons in this country in 1917. The net amount of coal employed in the production of gas light is said to be about one-quarter of that used for electric light. Let us recall that last winter we were told that a saving of 50 000 000 tons of coal would have to be effected in the country this year. It is understood that present indications now point to the need for an even greater saving, probably approximating 75 000 000 tons during the year. Let us note that if all electric and gas light were abolished with a consequent stoppage of nocturnal activity, the total coal saved would be only perhaps one-quarter or one-fifth of that which we must save during the coming year. The country employs for artificial light less than three percent of the coal output of the country. The proportion of the country's coal output which is consumed in electric lighting is represented in Fig. 1.

Artificial light has a very large place in our affairs. It facilitates and renders safe a wide range of industrial, educational and recreational activities which are of inestimable material and spiritual benefit to the country. Especially in time of war, when the human energies and material resources of the country must be mobilized and applied effectively, artificial light becomes an indispensable aid, the value of which is much more likely to be under-estimated than over-estimated.

FUEL SAVING

Notwithstanding the relatively small amount of fuel employed in the production of artificial light, it is incumbent upon all who can influence practice to labor assiduously in the elimination of waste in lighting to the end that a respectable fuel saving may be accomplished. The means to be used are principally as follows:—

Extinguish Lamps when They Are Not Needed—Needless operation of lamps, as those burning out doors in the day time, or those left burning in unutilized rooms at night, is the grossest form of waste which is encountered in artifical lighting.

Extinguish a Portion of the Lamps when the Full Illumination Is Not Required—It is advisable to have available a complete lighting equipment of reasonable capacity to meet the requirements in each installation. At times when the full illumination is not required, a portion of this may be ex-

tinguished without disadvantage. Often a rearrangement of circuits may make it possible to dispense with a part of the lighting on certain occasions while leaving the full installation for use when required.

Replace Inefficient by Efficient Lamps—Probably twice as many carbon and Gem lamps are used as could be justified on the ground of economy. While the Mazda lamp, especially in the smaller sizes, is too fragile to make possible a general replacement of the inefficient but rugged carbon and Gem lamps, yet in considerable part such replacement could be made with beneficial results. What has been said of electric illuminants applies with even greater force to gas illuminants where the mantle lamp could and should be installed in place of open flame burners to a large extent.

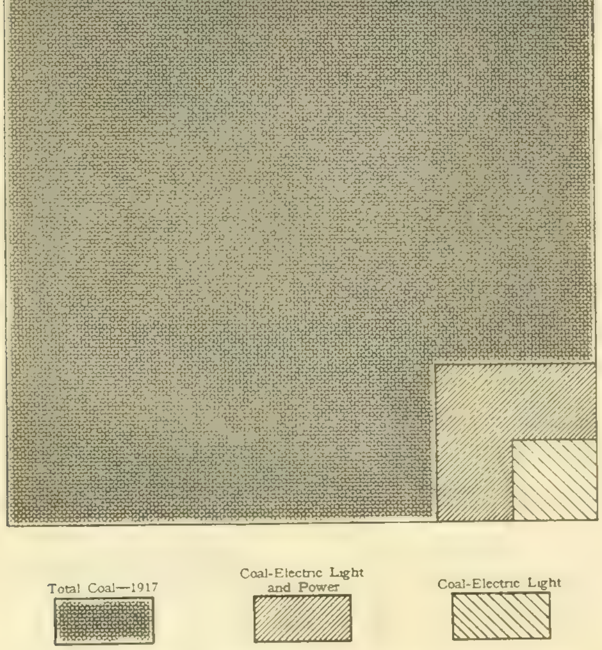


FIG. 1—COAL CONSUMPTION OF THE UNITED STATES

In gas lighting, however, as in electric lighting, the more efficient illuminant is fragile and unsuited for service in which the lamp is subject to shocks and vibration. This handicap makes impracticable a wholesale substitution of mantle lamps for open flame burners.

Use Efficient Accessories—It is often possible to effect a saving of a number of percent in the light which is utilized by substituting efficient for inefficient accessories. Globes of higher light transmission, reflectors which deliver a larger percentage of the light where it is required, accessories which do not collect dust, all promote economy.

Finish Surfaces in White Where Practicable—It is frequently possible to utilize 10, 20 or even 30 percent more light by refinishing reflecting surfaces such as ceilings, in good, light-reflecting colors. Such simple expedients result in a greater utilization of light.

Good Maintenance—Dust is one of the greatest causes of lighting inefficiency. Good maintenance of lighting equipments with reasonably frequent cleaning often effects considerable savings.

Whenever efficiency is improved, as by substituting efficient for inefficient lamps, by cleaning or by employing more efficient accessories, economy is promoted. In some cases more light is applied usefully to the improvement of working conditions while in others lamps of lower consumption are substituted, thus saving fuel.

If everyone connected with the lighting industry will exert his influence to secure all possible saving through these means, there will be placed to the credit of the industry and to the advantage of the country such saving as, it seems to the writer, to be practicable to effect in the artificial lighting field without serious disadvantage to the country.

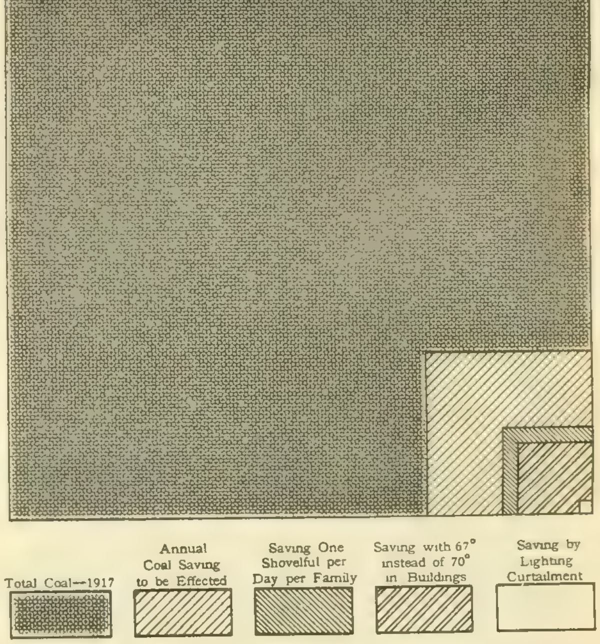


FIG. 2—SAVINGS IN COAL TO BE EFFECTED

READJUSTMENTS OF ARTIFICIAL LIGHTING AS AN ECONOMICAL MEASURE

A careful consideration of the possibilities of economical readjustment of artificial lighting with special reference to fuel saving will result in classifying possible lighting curtailment as follows:—

a—Reduction in lighting which would impair efficiency and which ought not to be undertaken in war time when the efficiency of the people is of special importance.

b—Reduction in lighting which can be made without impairing the efficiency of the people, but which would damage business and which ought therefore to be undertaken only in the face of imperative need for saving fuel which could not be saved otherwise with less disadvantage.

In the paper on lighting curtailment, there was presented a consensus of experts as to desirable readjustments of artificial lighting, taking into account war conditions, including fuel shortage. This is shown in Table I, the data being based upon the opinions of from twelve to twenty men.

This table reflects the conviction of illuminating engineers that, generally-speaking, too little artificial lighting is employed, that it would be to the advantage of the country to extend some classes of lighting systems and in some classes both to extend lighting systems and increase intensities. The tendency in artificial lighting has been in the direction of simulating daylight in respect to intensity, diffusion and hue. But it has been the practice to employ intensities which are very much below the daylight intensities which obtain, even in buildings where small window area results in a very limited admission of light. Not until three or four times as much artificial light is employed as in the recent past will these lowest of all daylight intensity values be reached. The relatively low prevailing intensities are on obstacle in the way of approximating the other qualities of daylight, in that light must be in part absorbed in the processes of diffusion and coloring, and until the use of light is sufficiently liberal to permit the necessary reduction in these processes without diminishing the light ultimately utilized below the point of practicability, general progress is impeded.

TABLE I—COMPOSITE OPINION OF DESIRABLE READJUSTMENTS OF ARTIFICIAL LIGHTING

[illegible] Service	[illegible]	Percent Adjust- [illegible] Intensities which [illegible] there were no Fuel Shortage	Percent Desirable Adjustments under [illegible] Conditions
Street (civic not white way) ...	14	+70	−5
Public buildings .	3	+100	10
Industrial	10	+175	+50
Protective	1	+100	+200
Commercial	22	+40	10
Residence	24	+30	−20
Recreational	7	0	−40
Advertising	4	0	−75
Miscellaneous . . .	6	+100	−10
Total	100		
Net		+72	−3

Usually, the liberal use of light is practiced where the return in dollars and cents is most directly traceable. It follows that light has been used most liberally in display advertising, including sign lighting, show window lighting, white way lighting, etc. The liberal use of light in these classes of service demonstrates the value of artificial lighting. In other classes of service, where the economic value of liberal use of light is less directly traceable, or where it has not been demonstrated to bring so direct a return to those who must bear the expense, the use of light on a liberal scale has not been so general. It is unfortunate that in this latter class are to be found those installations in which good artificial lighting ought to be made the agent of improved efficiency, which will count most directly in the interest of the country at this time.

INDUSTRIAL AND PROTECTIVE LIGHTING

Relatively few people appreciate that the liberal use of light is conducive to increased output, diminished shrinkage and safety, to an extent and in a way which directly affects industrial efficiency. Those contributing to the expression of opinion on this subject as summarized in Table I advocate on the average an increase of 50 percent in industrial lighting. This opinion was delivered at a crucial period of last winter's fuel shortage and in the face of the corresponding opinion that under pre-war conditions it would have been advantageous to increase industrial lighting by 175 percent. If it would have been to the advantage of the country to increase industrial lighting intensities by 175 percent before the war with a view to promoting industrial economy, it would seem that the desirability of such an increase is even greater in time of war, for industrial economy, especially if it leads to increased industrial output, is now of vital importance. It is the writer's belief that, if the experts who expressed these opinions were to meet at this time and discuss this subject, the resultant conclusion would be that at least the same increase in artificial lighting which they would have advocated under pre-war conditions ought now to be made in all important industries.

Protective Lighting for industrial plants devoted to work of importance to the public interest, for public works, for public utility plants, etc. is of great importance in making possible effective guarding of these properties. It is also a measure of economy, for with a good protective lighting system fewer guards can give the needed protection. In industrial and protective lighting there is found the greatest need for the increased use of light, and this need appears to be paramount to all considerations of fuel saving for reasons which will be discussed later.

Lighting of Public Buildings—In the lighting of public buildings, including schools, colleges, institutions, libraries, federal, state and municipal office buildings, etc. little or no reduction in lighting intensities can be made with advantage. Indeed, most such buildings are known to be underlighted. In the interests of economy, those in which work is performed ought to be lighted to a higher intensity. Most of the saving which can be effected in them is of a kind which has been endorsed unqualifiedly in this article, including extinction of lamps when not needed and the substitution of efficient for less efficient lamps.

Commercial Lighting—To that part of commercial lighting which includes buildings or rooms in which work is performed as, for example, offices, the same statements apply. In the remainder of commercial lighting, which includes stores, it would appear to be possible to accomplish some reduction without counteracting disadvantages.

Street Lighting—With display or white way street lighting relegated to its proper class, which is advertising, it may be said that all civic street lighting tends to be inadequate both in respect to intensity and extent, when judged from the police and safety standpoints.

Residence Lighting—It is often stated that too much light is used in residences. A residence is frequently thought of as a place for rest and relaxation.

Too often the fact that it is in considerable part a place of work is disregarded. A little reflection will make clear that a large percentage of the use of artificial light in the average home is in connection with the performance of some kind of work. It may be reading or sewing, or any one of a great variety of occupations, but all requiring the application of the eyes under the illumination provided. Especially is it important to remember that the home is the place where children do much of their school work. Generally speaking, homes are lighted inadequately for these purposes. To the extent that the home is a place of rest and relaxation, or is devoted to social activities, less light may be used without disadvantage. These two requirements tend to balance one another, resulting in the conclusion that little or no reduction in residential lighting can be advocated to advantage.

Advertising and Display Lighting—Adjustments of artificial lighting of the classes which have thus far been discussed have been considered from the point of view of effect of artificial light upon the activities of the people. Another important consideration is the effect upon the prosperity of those engaged in the lighting business. Like other patriotic industries, the lighting industry has manifested every desire to subordinate its direct interests to those of the nation as a whole. At the same time these private interests are of importance, not only to the lighting industry directly, but to the country at large, by reason of the widespread stock ownership of concerns engaged in the lighting business, and by reason of the dependence of the nation as a whole upon the prosperity of each of its business parts. Curtailment of advertising or display lighting can probably be accomplished with less disadvantage to the people than curtailment in any other branch of lighting. If fuel shortage is such as to demand serious sacrifices through artificial lighting, curtailment, this class of lighting naturally receives first attention. It is a class in which damage to the business interests affected constitutes the principal objection to curtailment. Both the lighting industry, with whose business it would interfere seriously, and the commercial interests which have prospered through this form of advertising would suffer through such curtailment. The loss which would be inflicted ought to be weighed against the disadvantages which would be incurred in effecting the same fuel saving through economies or curtailment in other directions.

ESTIMATE OF NET PRACTICABLE LIGHTING CURTAILMENT AND OF CORRESPONDING FUEL SAVING

In Table I, the column presenting the consensus of opinion in regard to desirable readjustments of lighting in view of the war and the coal shortage, indicates a net reduction in artificial lighting of the order of three percent. The estimate of coal consumed in electric lighting is 12 000 000 tons per annum. If a curtailment of this extent be assumed to accomplish a proportionate saving in coal consumption, the net saving per annum will be 360 000 tons. As previously stated, it is the author's opinion that a full consideration of the facts would indicate that even this extremely small saving would prove undesirable for the reason that economy dictates a more liberal use of light in industrial work which, if effected, would more than wipe out the net saving here indicated.

It may be objected that these considerations are academic for the reason that, in the face of a serious coal shortage, savings must be effected and lighting must be curtailed for the simple reason that coal is not available with which to do all the lighting. The answer to this objection is that much greater savings of coal may be accomplished in other directions with lesser disadvantage or even with advantage. Why curtail lighting, incurring the danger of impaired efficiency of the nation, and damaging a part of the country's business in order to save a little coal, when a great deal more coal can be saved otherwise with little or no disadvantage? Some estimates of such greater savings are as follows*:—

Savings within the control of the public—	
Saving if each family decreases by one shovelful its daily use of coal	15 000 000 tons
Saving by maintaining temperature of building interiors 3 degrees lower, say 67 degrees instead of 70 degrees F....	10 000 000 tons
Possible savings not within control of the general public—	
Saving by railroads through practicable light firing of locomotives	7 000 000 tons
Practicable savings requiring some time for consummation and not within the immediate control of the general public—	
By railroads through electrification	40 000 000 tons
Accomplished by Chicago, Milwaukee & St. Paul Railway through electrification and utilization of water power on its Rocky Mountain Division	500 000 tons
By substitution of central station power for private plants	13 000 000 tons

These relations are expressed graphically in Fig. 2.

CONCLUSION

In the readjustment of artificial lighting to serve the best interests of the nation, patriotism demands economy. Economy consists in the elimination of wasteful lighting, and in the more liberal and extensive use of light where this can be made to promote efficiency. Artificial lighting should not be looked to for more than an inconsiderable part of the total coal saving which must be accomplished. All concerned ought to exert themselves to accomplish as much coal saving as possible and to promote efficiency wherever possible through readjustments of artificial lighting.

*For sources of data here see paper on "Lighting Curtailment", p. 111, *Transactions Illuminating Engineering Society*, March 20, 1918.

Recent Protective Relay Developments

E. A. Hester

In the last few years as electrical apparatus has continued to grow larger and distributing systems more complicated, protective relays have begun to occupy a place of prominence in the equipment of generating stations and distributing systems. One factor which was largely instrumental in making them necessary, was the rising cost of copper, with the attendant expense of installing duplicate feeders in order to give continuity of service to important customers. Economical use of copper became a necessity and by using the proper relays, transmission lines could be connected in parallel by groups, in loop or ring fashion, or as a network, thus giving more economical and better service than could be obtained by using duplicate radial feeders. In this way each receiving station may have two or more sources of power; in case of trouble on one line the others are still available, and yet all the lines are in use continually.

In order to make such operation feasible it was evident that relays must be devised which would infallibly cut out a defective line before the trouble could spread to the good sections. This ideal has not been attained, but enormous steps have been taken in that direction.

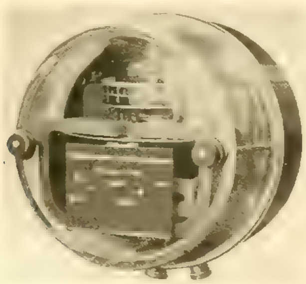


FIG. 1—INDUCTION TYPE TEMPERATURE RELAY

The first protective relays were of the solenoid overload type so constructed that when excessive current flowed, a plunger was lifted, tripping the circuit breaker mechanically, or accomplishing the same purpose by making or breaking a circuit through the circuit breaker trip coil. This, however, could be used only on radial lines. In order to operate lines in parallel, a relay was necessary which would operate only in case of trouble with reversal of power. This was brought out and put in successful operation, permitting a more efficient system of distribution. Following this, different types of relays, both overload and reverse power, were produced. Most of these have given a fair degree of satisfaction, but the induction type has proven itself to be the most satisfactory and has practically superseded the others. Constant effort has been put forth toward improving these relays and now their accuracy and permanence of calibration enable operating conditions to be obtained which approach the ideal. Ways and means of attaining this degree of protection have been described in former articles.*

Besides developing relays for the purpose of protecting lines in case of trouble, considerable study has been devoted to other phases of protection. Relays are now available which furnish adequate protection against overheating, power reversal, over or under-voltage and phase reversal. Auxiliary relays have also received their share of attention, the most important development among these being the direct trip or transfer relay, which enables the use of current directly from the secondary of the series transformer for tripping, thereby obviating the necessity of an auxiliary direct-current control circuit.

TEMPERATURE RELAYS

When a piece of electrical apparatus is subjected to abnormal load conditions, overheating takes place and it is the purpose of the temperature relay to disconnect this apparatus from the remainder of the circuit before any harm is done. It is not desirable to disconnect the apparatus upon a momentary overload nor if there is any possibility of the overload being removed before the temperature reaches a dangerous value. Therefore in order to fulfill all requirements the relay must operate only upon a combination of high temperature and excess current. Several schemes have been tried and have been put in operation with varying degrees of success.

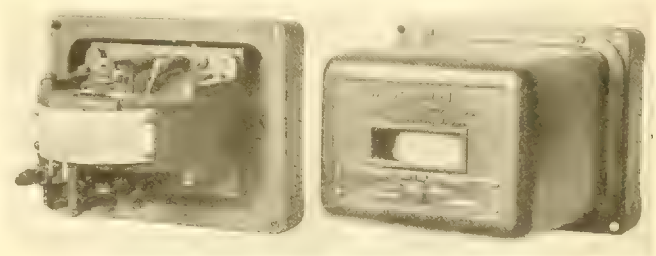


FIG. 2—MOVING-COIL TYPE TEMPERATURE RELAY

Relays have been built using some material which expands upon a rise in temperature and so arranged that, after a definite time, a circuit is closed by the expanding element, thus opening the circuit breaker. Mercury is sometimes used for this purpose but a bimetallic element, consisting of strips of brass and steel rigidly fastened together, is usually employed. This of course gives a good time lag but has the disadvantage that it is very difficult to get consistent operation. The arrangement is usually such that a current proportional to the load current flows through a small heater located

*"The Protection of Transmission Circuits by Relays", by F. E. Ricketts, in the Journal for April '14, p. 227. "The Selective Time Element of Relays", by Paul MacGahan in the Journal for March '15, p. 91. "Reverse Power Relays", by Paul MacGahan and B. H. Smith in the Journal for Sept. '15, p. 417. "The Use of Protective Relays on Alternating-Current Systems" by L. N. Crichton in the Journal for July '16, p. 330.

in the relay which, if the relay element has the same temperature gradient, gives the same temperature condition as that of the apparatus to be protected. Another scheme was to use a metal which loses its magnetism upon an excessive rise in temperature, but difficulties were encountered and the device proved unsatisfactory in operation.

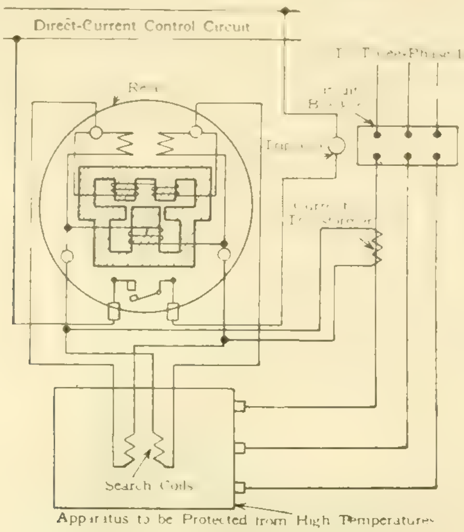


FIG. 3—CONNECTIONS OF TEMPERATURE RELAY
For protection against simultaneous overloads and excessive temperatures

Finally a type was developed which, by using the Wheatstone bridge principle, eliminates the difficulties present with those operating on the other principles. A Wheatstone bridge is made to take the drop across the main field windings of the relay as shown in Fig. 3. Two arms of this bridge are of unchanging resistance and the other two are formed by copper search coils arranged to be embedded in the apparatus to be protected. It is evident that the temperature of the search coils will depend on three things:—

1—The temperature of the substance surrounding the coils.

2—The current flowing at that particular instant.

3—The heat which has been generated in a previous overload but which has not yet been dissipated.

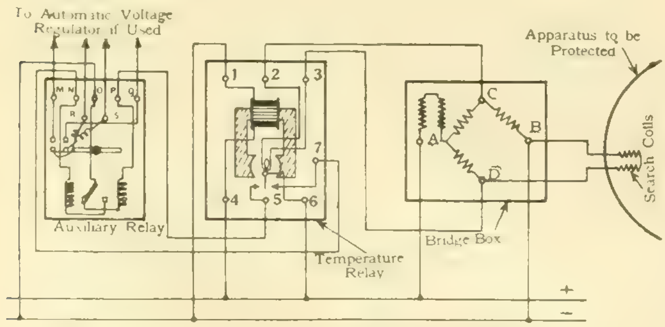


FIG. 4—CONNECTIONS OF TEMPERATURE RELAY
For protection against excessive temperatures. If the auxiliary relay is used to trip the circuit breaker, leads *M* and *Q* are connected to one side of the trip circuit and leads *R* and *S* to the other side.

Thus all conditions are taken care of whether it is a large overload for a small interval of time, a small overload for a longer interval of time or excessive overloads occuring at frequent intervals so as finally to cause a dangerous temperature rise. Then, since the resistance of these search coils depends upon their temperature, the current flowing in the conventional galvanometer circuit is governed by the temperature of the apparatus to be protected. Therefore if the main winding of an excess current relay, arranged to operate at very low current, is substituted for the galvanometer a relay is obtained whose action depends upon the temperature rise of the protected apparatus. Also if connections are made as in Fig. 3 the operation of the relay depends also upon the current flowing in the apparatus. Nor will it operate on the effect of either alone, but only upon a combination of the two.

The resistance of the search coils is so chosen that when a definite temperature is reached they have a resistance which balances the bridge arms. For temperatures below this critical value, the torque is in the contact-opening direction of the relay while for those above it, the torque is in the contact-closing direction.

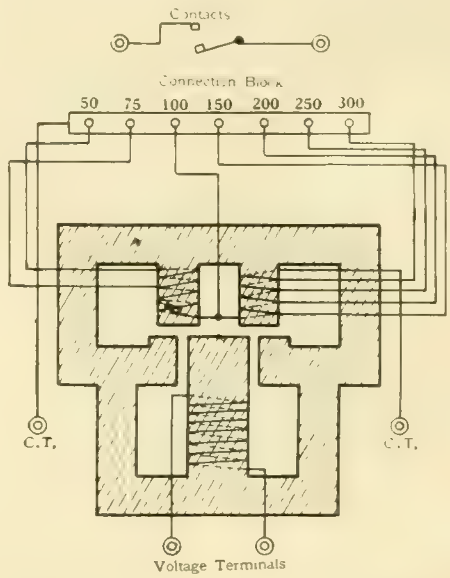


FIG. 5—INTERNAL CONNECTIONS OF WATT RELAY

In case of excessive temperatures caused by an overload, the operation is as follows:—Assuming that the apparatus is operating under normal conditions and an overload occurs, the current flowing in the bridge circuit increases, and the current in the excitation circuit of the relay, which is in parallel with the bridge, increases proportionately. But since the resistances of the search coils are the same as of the other two arms, no change in current value takes place in the main field windings (the galvanometer circuit) of the relay. If the overload persists, however, the temperature of the apparatus goes up, increasing the resistance of the search coils and thereby increasing the current flow in the main field windings of the relay. Should these conditions continue, the current in the relay will grow larger as the temperature rises until finally it becomes sufficient to trip the circuit breaker. If the overload should increase in the meantime, it would produce the added effect of increased current flow in the bridge

circuit, which is highly desirable, causing as it would quicker operation. Should the overload be removed before the relay operates the excitation will decrease and also the current in the bridge will decrease to such an extent that the unbalance will not force sufficient current through the relay to cause it to operate.

This device is connected directly to the current transformer in the main circuit and the two unchanging bridge arms are enclosed in the relay case. The relay is of the overload induction type with special low current windings and is provided with a time adjustment. As shown in Fig. 1, it is enclosed in a metal case with glass cover and arranged for standard switchboard mounting. Its contacts will open five amperes satisfactorily and it can be provided with an internal contactor switch for larger tripping currents. The relay is intended to protect stationary apparatus but may be used

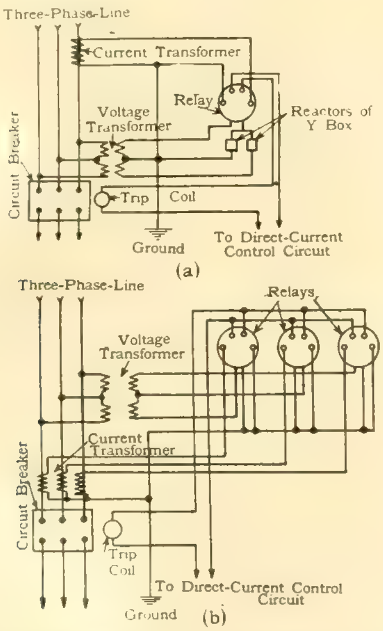


FIG. 6—EXTERNAL CONNECTIONS OF WATT RELAY

(a)—Using one relay and *Y* box for a three-phase balanced circuit. (b)—Using three relays for a three-phase unbalanced circuit.

to protect any alternating-current apparatus in which search coils can be properly installed.

There is another type for use with a small copper search coil which may be embedded in the windings of a rotating machine. It operates on the same principle as the device described above except that one search coil and three unchanging bridge arms are used and a direct-current relay is connected across these as shown in Fig. 4. An auxiliary direct-current control circuit is used as a source of operating current and the resistance of the search coil is so chosen that the bridge balances at the critical temperature of the machine. At this critical temperature the relay operation is independent of the voltage but at all other temperatures the accuracy of the relay depends upon the voltage of the auxiliary circuit. Therefore it is calibrated at two voltages representing the extreme operating voltages of the circuit.

In operation this scheme differs from the other in that it is controlled only by the temperature of the apparatus to be protected. As in the other type a rise in temperature unbalances the bridge causing sufficient current to flow in the relay to operate it. The relay is of the standard moving-coil type, having its field produced by an electromagnet the coil of which is connected across the auxiliary circuit. Special windings are provided making the relay sensitive to small changes in current. Views of the relay are shown in Fig. 2.

Owing to the great sensitiveness of this type of relay, small contacts are required, and it is necessary to use an auxiliary relay connected as shown in Fig. 4. The relay is provided with two contacts which close at definite values of high or low temperature. The auxiliary relay is so arranged that connections may be made to a voltage regulator which it controls and the temperature of the machine is controlled by changing the volt-

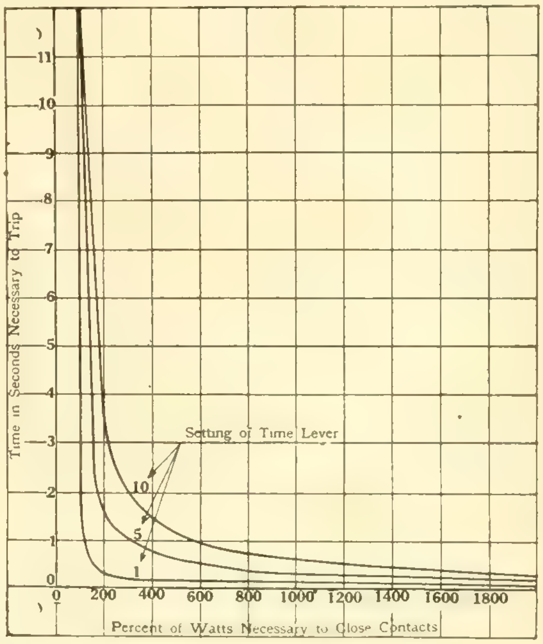


FIG. 7—CHARACTERISTIC LOAD-TIME CURVES OF WATT RELAY

Showing the effect of various time lever settings and the range of adjustment which is available in setting the relay, to prevent operation on momentary overloads.

age supplied. This auxiliary relay, while arranged with connections for a voltage regulator, may be used to trip a circuit breaker. The temperature relay may also be arranged so that the low side is not used.

Both these devices provide a simple means of protection against overheating, are easy to adjust and adjustments once made are permanent.

THE WATT RELAY

The ordinary reverse power relay, as used to protect incoming ends of transmission lines, will operate on a reversal of power provided there is sufficient current to actuate the overload element. But in order to prevent it from operating on small momentary reversals which are apt to occur at any time, the current setting of this overload element must be made comparatively high. There is a demand for a unidirectional relay which will close its contacts on a power reversal at low current; but in order to adapt a standard reverse power

relay to this service an impractical design of the overload element is necessary, to allow the full-load current in the normal direction to flow. Yet the need for such a relay is apparent. For instance, a company using a large amount of power has a small plant capable of carrying only part of the load, the remainder being bought from a distributing system. The two are connected in parallel and in case the larger plant is shut down it is necessary to prevent the smaller plant from trying to take its load. Such a condition would of course cause a reversal of power on the customer's incoming line. If standard reverse power relays are used, an excessive flow of power is necessary in order to cause them to trip out the circuit breaker. The voltage will be approximately normal and yet sufficient current will have to flow to operate the overload element.

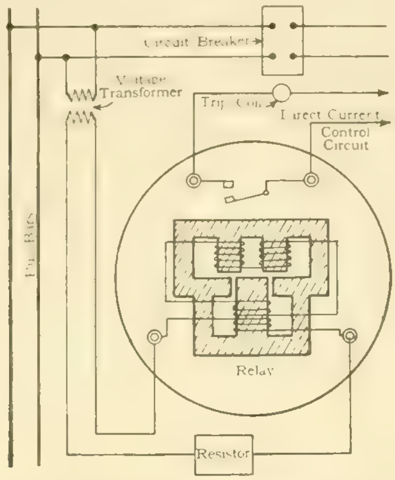
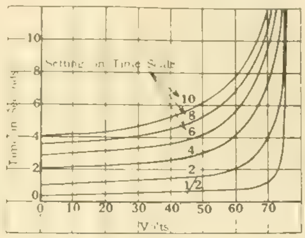


FIG. 8—CONNECTIONS OF VOLTAGE RELAY

This difficulty can be overcome by using an induction relay having a watt element acting upon a single disc damped by permanent magnets. This gives the combined effect of normal voltage and reverse current acting upon a single element, thus requiring a smaller current to operate it. Nor will it close its contacts upon a comparatively small momentary reversal. Such a relay has recently been developed, having an adjustable range of from 50 to 300 watts, which fulfills all ordinary requirements. The internal connections of this relay are shown in Fig. 5 while Fig. 6 shows how it is connected into the circuit. One relay is required for a single-phase circuit, two for a two-phase circuit and three for a three-phase unbalanced circuit. If a three-phase circuit is balanced a single relay may be used as shown in Fig. 6 (a), with two reactances of proper value connected in star with the voltage coil of the relay.

FIG. 9—INDUCTION TYPE VOLTAGE RELAY

This relay is calibrated in watts and taps are brought out from the current coils and carried to a seven hole terminal block, so that by inserting the contact screw in any one of these holes the relay will operate when a corresponding amount of power flows. Thus by the proper selection of instrument transformers, the relay may be set to operate for any reasonable value of power flow in the main circuit. The figures on the terminal block represent the minimum watts at which it will operate but, at any power setting, the time of operation will be inversely proportional to the power flow.



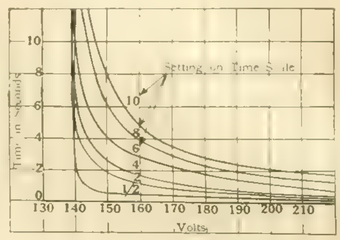


FIG. 10—CHARACTERISTIC CURVES OF UNDER-VOLTAGE RELAY FIG. 11—CHARACTERISTIC CURVES OF OVER-VOLTAGE RELAY
Showing variations with time scale settings. Normal voltage of circuit, 110 volts.

The watt relay is also provided with a time adjustment controlled by a lever, which limits the motion of the disc, therefore the distance the contacts travel before closing. This lever moves over a scale divided into ten arbitrary divisions and by reading the values from the characteristic curves shown in Fig. 7, any desired time setting may be obtained. These curves show the time of operation for different percentages of power settings with the lever set at *10*, *5* and *1* on the scale. Such a relay operates on a small reversal of power and may be set for any desired value of time or power. The time adjustment is particularly desirable since it is necessary to prevent operation on momentary reversals. Except for name plate marking this relay presents the same appearance as the temperature relay shown in Fig. 1. It has all the desirable characteristics of an induction type relay and once adjusted requires no further attention, other than inspection.

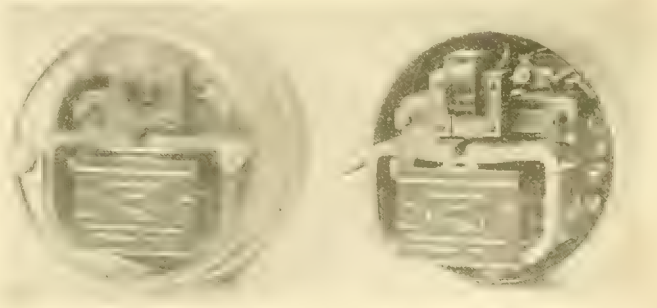


FIG. 12—VOLTAGE-OPERATED, CIRCUIT-CLOSING TYPE OF REVERSE PHASE RELAY

VOLTAGE RELAYS

When a piece of electrical apparatus is designed to operate at a specified voltage, it is often necessary to

disconnect it from the source of power, should the voltage rise above or fall below certain predetermined points. This is most conveniently done by using a relay, such as shown in Fig. 9, to close the tripping circuit of the circuit breaker. This relay is of the induction type, having a time element controlled by permanent magnets acting upon the disc of the moving element. The winding is the same as the ordinary induction-type overload relay, except that voltage instead of current windings are used. The torque compensator and terminal block are omitted, so the relay is not adjustable after calibration, as regards voltage. It is of the circuit closing type having silver contacts capable of tripping currents up to five amperes. For currents in excess of this a special internal contactor switch may be used which will interrupt currents as high as twenty amperes. It is calibrated so that it will close its contacts at any specified voltage, either above or below a definite value, provided this value is not outside the limits of adjustment. Closing values usually chosen are 70 percent normal and 130 percent normal for undervoltage and overvoltage service. A time adjustment is also provided which is the same as that on the watt relay. Connections are shown in Fig. 8. A potential transformer is necessary for circuits higher than 220 volts. With the undervoltage relay, connections are made in such a way that the torque is in the contact opening direction while with the overvoltage type the torque is in the opposite direction. In the former case the contacts are closed when the tension of the disc spring overcomes the torque, while in the latter type the torque is made to overcome the spring tension. In both cases the disc is so constructed that the torque is proportional to the spring tension, thus giving the correct time element. Curves showing the characteristics of the overvoltage type are shown in Fig. 11, and Fig. 10 shows the characteristics of the undervoltage type.

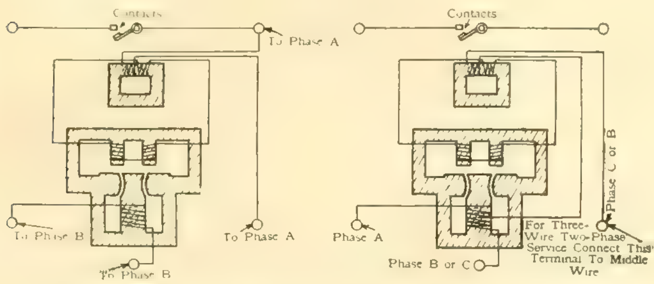


FIG. 13 INTERNAL CONNECTIONS OF REVERSE PHASE RELAY
For two-phase circuits on the left and three-phase on the right.

REVERSE PHASE RELAY

Reversing any two wires of a three-phase motor circuit, or the wires of either phase of a two-phase motor circuit will cause the direction of rotation of the motor to be reversed. Such a reversal may occur at any time due to an interchange of conductors while repairs are being made to the line between the motor and source of power. This may also occur due to repairs or changes being made in the switching and controlling apparatus. In any case the direction of rotation of the motor will be changed and, when driving certain classes of machinery, such a condition may lead to disastrous results.

It is the function of the reverse phase relay to open the circuit should such a condition occur, and prevent injury to the operator, machinery or manufactured product. Such a relay is shown in Fig. 12. It is of the voltage operated, circuit-closing type and is built for either two or three-phase operation. The arrangement of the electrical and magnetic circuits, for both the two and three-phase types is shown in Fig. 13. As can be seen the electrical element of the relay is composed of a laminated steel electromagnet the coils of which are connected across the phases as shown. A diagram of the external connections is shown in Fig. 14. The coils are so arranged that a rotating field is set up, which acts upon a disc, placed in the air gap of the electromagnet, producting a torque in a direction dependent upon the direction of phase rotation. Thus by properly connecting the relay the contacts are held open until a reversal of phase occurs, when the relay trips the circuit breaker.

The relay is mounted in a dust proof metal case with glass cover and is provided with the necessary studs for switchboard mounting. Its contacts will handle five amperes tripping current, but for higher values an auxiliary switch must be used.

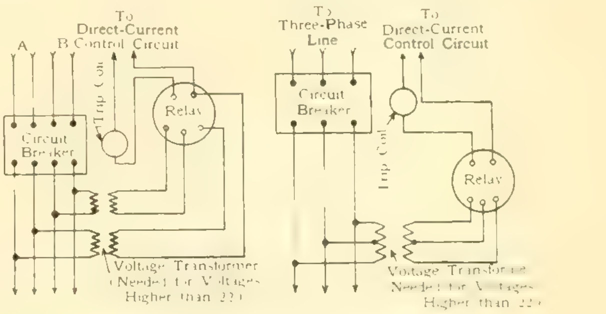


FIG. 14—EXTERNAL CONNECTIONS OF REVERSE PHASE RELAY
For two-phase circuits on the left and three-phase on the right.

THE TRANSFER RELAY

At times when there is no source of direct current for tripping purposes, it is necessary to trip the circuit breaker by means of current taken from a series transformer on the main line. In order to satisfy such requirement a device known as the "direct trip attachmen" was developed. The arrangement of its magnetic and electrical circuits, as shown in Fig. 15, is as follows. At the bottom of the circuit breaker trip coil is attached an iron yoke having two coils, one known as the holding coil which is constructed of a relatively small number of turns of large wire and the other known as the releasing coil, which is composed of a great many turns of small wire. The holding coil is connected in series with the circuit breaker trip coil and the current coil of the primary relay, all being connected in the secondary of the current transformer. The releasing coil is connected across the contacts of the primary relay.

At normal operation the position of the trip coil plunger is as shown in the diagram. So long as the releasing coil circuit is open the plunger will remain in

this position, the upper or trip coil having an inductive shunt connected across its terminals to prevent its pull becoming too great at high currents. As soon, however, as trouble occurs on the line and closes the primary relay contacts, thus short-circuiting the releasing coil, a transformer action is set up which demagnetizes the lower yoke and allows the trip coil to lift the plunger and trip the circuit breaker. This device operates very satisfactorily but has the disadvantage that it must be mechanically connected to the circuit breaker. Quite a little trouble is experienced in attaching it to some types, and in order to overcome this difficulty another device known as the "direct trip relay" or "transfer relay" was developed. This relay operates on the same principle as the direct trip attachment, the only difference being that a yoke with the upper coil is substituted for the circuit breaker trip coil and the plunger rod is made to operate a transfer switch which shunts the secondary current of the series transformer through the circuit breaker trip coil, when the primary or overload relay closes its contacts. A view of this relay is shown in Fig. 16 and the method of connecting it to a three-phase circuit, using one trip coil and three transfer relays is shown in Fig. 17. The arrangement of the magnetic circuit and internal connections may also be seen from Fig. 17.

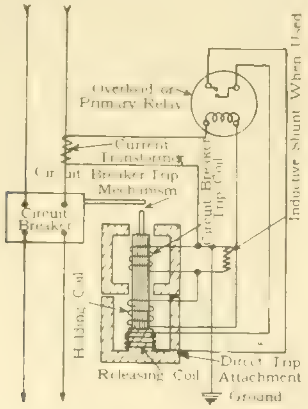


FIG. 15—CONNECTIONS OF DIRECT TRIP ATTACHMENT TO CIRCUIT BREAKERS

Showing electrical and magnetic circuits.

FIG. 16—TRANSFER RELAY

Used to trip the circuit breaker by electrical rather than mechanical means.

The transfer switch used in this relay is of the sliding type with large copper contacts and performs the shunting operation without opening the secondary circuit of the series transformer. It will handle trouble current for all conditions of short circuit and is self reset after an operation. The transfer relay is rated at five amperes and will operate with four amperes flowing in the series transformer secondary, provided the releasing coil is short-circuited, but unless this is done the relay will not operate regardless of the current flowing. By using this transfer relay all the difficulties experienced in making the mechanical connection between the circuit breaker and direct trip attachment are eliminated. The only connection is an electrical one and the relay may be mounted on the switchboard in any desired location.

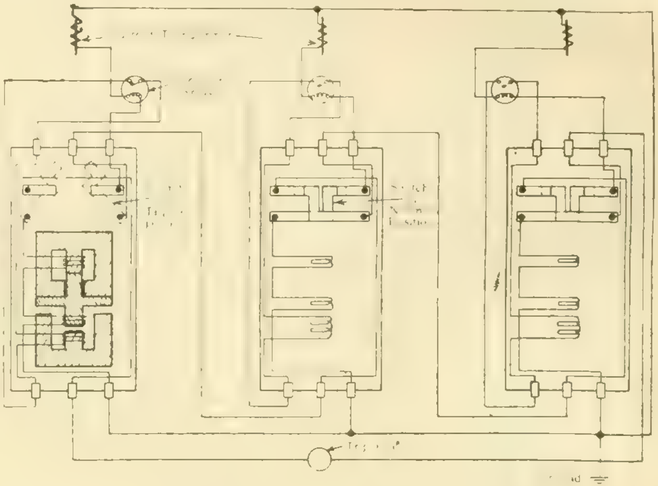


FIG. 17—INTERNAL AND EXTERNAL CONNECTIONS OF TRANSFER RELAY

Showing transfer switch in tripping and in normal position. The switch is shown in schematic rather than actual form. In the normal position, current passes from the upper right to the lower left terminals and from the upper left to the lower right terminals, the two circuits being insulated from one another.

Choice of Current for Mazda Series Lamps

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Westinghouse Electric & Mfg. Company

SERIES STREET LIGHTING systems have been operated at various currents, ranging from 1.75 amperes with carbon incandescent lamps to 20 amperes with some of the flame carbon lamps. The ratings chosen with arc lamps varied with the different types as developed to secure the best operation of the lamp mechanism and electrodes, and to secure the amount of light desired. The current ratings most commonly in use in this country were chosen to meet arc lamp development as follows:—

4. amperes metallic flame arc requiring direct current.
5.5 amperes enclosed carbon arc.
6.6 amperes open carbon, enclosed carbon and metallic flame arc.
7.5 amperes enclosed carbon arc.
9.6 amperes open carbon arc.
10. amperes flame carbon arc.

The only incandescent lamps used in any quantity for street lighting at the present time are Mazda C, which are regularly furnished in current ratings of from 3.5 to 7.5 amperes and in sizes from 60 to 600 candle-power. There are also the 400 candle-power, 15 ampere and 600 and 1000 candle-power 20 ampere lamps intended to be operated by an autotransformer from the standard line current.

The choice of line current for a Mazda system is affected very often by the machinery already on hand, which has been used to supply current to arc lamps and by the supply of street series lamps already on hand. Many of these systems can be changed over from current ratings of 3.5 or 4 amperes to ratings of 6.6 or 7.5 amperes, so that lamps more desirable from an operating and manufacturing standpoint may be used.

The mechanical strength of the line rather than its resistance or current capacity usually determines the size of the wire. The curves in Fig. 1 are based on an arbitrary assumption of a circuit having an average spacing of 500 ft. for the lamps and using No. 6 wire. They show that, with the small lamps, for example the 60 candle-power, the proportion of the line loss is relatively high, indicating at once the desirability of using as large lamps as can profitably be employed.

INCANDESCENT LAMP FEATURES

Street series lamps are rated to burn 1350 hours under test conditions, this basis being calculated to give the most light for the cost of power and lamp renewals entering into the expense of light. The candle-power rating is arbitrarily given as 10 percent of the total lumens emitted by the filament. The lumens are measured by means of a spherical photometer, this being the only method of measuring Mazda C lamps consistently. Assuming that the rated candle-power is equivalent to the mean horizontal candle-power, the reduction factor with usual arrangements of filament is approximately 79.5 percent.

With a fixed candle-power, current and life rating, the voltage of the lamp is determined by experiment and the lamp so rated. For low current, a relatively small diameter filament is used. The radiating surface of the filament is, therefore, comparatively large, causing the loss of energy as heat carried off through the gas in the lamp. By using large currents, larger filament may be used and radiation be reduced. By reason of this fact, the efficiency of the 6.6 amperes 100 candle-power lamp is 20 percent higher than that of the 75 watt, 110 volt lamp, giving approximately the same candle-power. Similarly, the 600 candle-power 20 ampere lamp has 26 percent higher efficiency than the 110 volt 400 watt lamp of approximately the same candle-power.

However, the design of lamps involving the use of high current and filaments of large diameters and short length cannot be carried to an extreme, for the reason

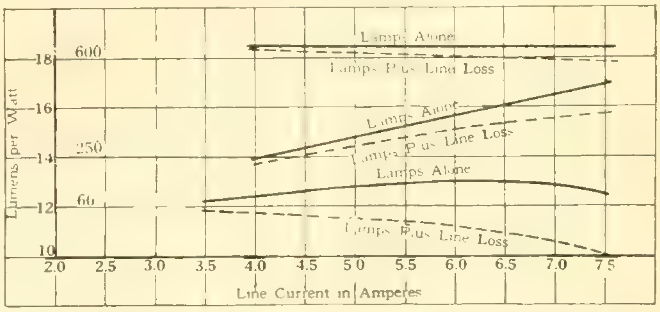

FIG. 1—RELATION OF LUMENS PER WATT TO LINE CURRENT OF SERIES STREET LAMPS

For 60 250 and 600 candle-power lamps. The line loss is made up of 500 feet of No. 6 wire. The curves for the 600 candle-power lamps include an autotransformer loss of 15 watts per lamp.

that, if the filament be too short because of the low voltage required across the lamp terminals to give the required wattage, an undue proportion of energy will be lost as heat conducted away through the leading-in wires. The curves show the effect of these factors in the ratings of the standard lamps. They also show the great desirability of using not less than 60 candle-power per lamp, because in smaller sizes not only is the lamp design much poorer, but the percentage of the line loss rapidly increases.

STANDARDIZATION

For simplicity in operation, manufacturing and the carrying of stock, one single current is desirable for all systems. For general purposes, the 6.6 or 7.5 ampere systems meet these requirements best. Much of the distribution apparatus used with street lighting systems

for enclosed carbon arc lamps and Mazda B lamps is of this rating, the 6.6 ampere predominating. It is, therefore, highly advisable now that the lamps are standardized to a great extent that central stations operating odd ratings use every effort to change them to standard. The coils of regulators and their instruments can be changed with relatively small difficulty. The equipment of shunt coils and transformers for an adjuster socket system are only slightly more difficult to change. By changing one circuit at a time, the old lamps can be used up on remaining circuits, so that practically none will have to be discarded.

Protective Lighting for Manufacturing Plants

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That a protective lighting system is necessary as a means of defense against possible attempts by enemy agents to damage the plant is generally admitted, and there are now very few factories engaged directly or indirectly in manufacturing materials for the Government which have not installed additional lighting units in and about the plant in order to make it easier to guard the premises at night. This problem of lighting the grounds and buildings for protection was a new one to most plants, however, and as it was one which had to be solved in a hurry, it is not surprising that the best results were not always obtained and that many of these protective lighting installations are not as effective aids to the guards as they might be.

It is evident that, if there were no lighting for purposes of protection, it would be almost impossible for the guards to detect and prevent attempts to damage the plant but, unfortunately, it is not quite so evident to the average man that the installation of additional lighting units, without regard to the glare they produce or the way in which the light is distributed over the area to be guarded, may result in the condition which is practically as bad as no light at all. Simply lighting up the factory grounds at night cannot be counted upon to scare off a determined and intelligent enemy agent, and the system should, therefore, be designed to afford maximum assistance to the guards in their work of detecting suspicious activities about the plant.

To be effective, a protective lighting system should illuminate the areas to be guarded in such a way that the guards can see what is going on, preferably without being themselves revealed, and should also illuminate an area around the boundaries of the plant so that no one may gain access to the grounds without being detected. Also, the system should be so installed that the possibility of failure at a critical time is reduced to a minimum. Just what type of lighting units should be used to accomplish these results and where and how they should be installed depends entirely on local conditions and it is impossible to develop a standardized form of installation which can be used everywhere.

An analysis of protective lighting systems which do not give a proper measure of protection shows, however, that this is usually due to definite and easily recognized faults and it is the purpose of this article to point out some of the more commonly found faults and to suggest remedies. Many times an inspection of the lighting system made from the outside of the plant reveals the fact that the lighting units have been installed in such a way that the guards on fixed posts are stationed in brightly lighted areas or that guards have to cross brightly lighted areas in making their rounds. Such conditions should be avoided as far as possible, not only because the guards are then very conspicuous but also because it is always hard for a man in a brightly lighted area to see, clearly, objects which are in the surrounding darker area, and the work of the guards is therefore made more difficult.

In most cases fixed posts do not have to be located directly under lamps, as they frequently are, but can be located far enough away from the lamp so that the guard is in comparative darkness. If, however, conditions are such that the guard must be stationed near a lamp, for instance at an entrance, the lamp may be equipped with an opaque reflector of an angle type turned so that the light will be directed away from the guard. When the entire factory yard is well lighted so that there are no really dark areas it may be impractical to arrange matters so that the guards who patrol the premises do not cross lighted areas. Under ordinary conditions, however, the distribution of illumination over the yard is such that certain areas are less brightly lighted than others, and the guards should walk in these areas as far as possible in order that they may escape observation themselves and at the same time be in a more favorable position to see what is going on in the brightly lighted areas.

A survey of the lighting made from the outside may also show that the illumination of the area to be guarded is very non-uniform with large dark areas and sharply defined bright spots. Frequently the dark areas, in which a man might well escape detection, extend from the boundaries of the plant well into the grounds, and the bright areas are so clearly defined that they could easily be avoided. Such a condition may be due to the fact that not enough lighting units are being used, and that they are too widely spaced, with the result that

the lighted area is not continuous but there are areas between lamps which receive very little light. Or when floodlighting units are employed it may be due to an attempt to cover a wide area with a few projectors which produce narrow high intensity beams. This condition is always a particularly bad one because the spot of light is very bright and in great contrast with the surrounding darker areas, and is moreover usually comparatively small. When in such an area a man would, of course, be clearly revealed, but when he steps out of the spot of light he almost disappears from view in many cases. Frequently an attempt is made to widen the spot of light by moving the lamp out of the focus of the mirror in the projector. This will result in spreading the beam somewhat but if the lamp is moved too far out of the focus of the projector there will be a dark area in the center of the projected beam of light and the illumination obtained on the ground will be unsatisfactory. There are now available several types of projectors designed to produce beams somewhat wider than those which could be obtained with the projectors first put on the market and these should be used when a wide beam of light is necessary.

With regard to the lighting of the grounds, as considered from the standpoint of the guards who patrol the premises, it is frequently found, even in cases when the illumination on the ground is reasonably uniform and apparently of sufficient intensity to reveal a man, that there are, nevertheless, parts of the area to be guarded in which a man might easily escape detection when the guard is at certain points in his rounds, although he might see the man quite plainly from another point. This condition is usually caused by the presence of bright unscreened lamps within the guard's field of view, when he looks toward these areas, which produce a sufficient degree of glare to make it difficult and sometimes impossible for him to see objects between himself and the lamps which are producing the glare. Such a condition may be caused by a very intense high candle-power beam of light from a distant projector or by bright unscreened lamps of comparatively low candle-power near-by. Just how much glare can be tolerated will depend upon local conditions but in most cases there will be found to be a surprisingly small amount, particularly in exterior lighting where the surroundings are dark and the average illumination is necessarily low, and the contrast between the bright lamps and the background is therefore very great.

For this reason flood-lighting must be used very carefully for illuminating factory yards, particularly when the beams of light are directed on the area to be lighted from several directions, as it is difficult to place the projectors so that they will not produce annoying glare. This is particularly true when local conditions make it impossible to mount the projectors very high above the ground. Glare from near-by lamps of the ordinary type is usually caused by mounting the lamp too low and using no reflector or globe, or a very flat type of reflector which does not screen the lamp filament from the observer's eyes in an effort to get a sufficiently wide spread of light. The remedy is to mount the lamps higher and to equip them with reflectors of the dome type, which will direct most of the light downward and so materially increase the illumination in the area to be guarded, over that which would be obtained from bare lamps.

Frequently there are dark corners or passage-ways between buildings which are so poorly lighted that it is almost impossible to see into them and for this reason they are not carefully inspected by the guard as he makes his rounds. These places, particularly when near buildings, should be lighted and this can usually be done by installing small lamps in reflectors. When it is not feasible to install lamps much can be accomplished by the use of white or light colored paint which will provide a background against which objects will be visible. Too little attention has been paid, in designing protective lighting systems, to the possibility of utilizing light colored backgrounds to improve visibility where the illumination is low because of the idea that protective lighting is entirely a matter of lamps and reflectors. We see an object when the contrast between it and the background is sufficient to make it stand out, which may be because the object is brighter than the background or because the background is brighter than the object. When the object appears brighter than the background it may be because more light falls on it than falls on the background or because it is of a lighter color than the background and therefore reflects more light. Similarly, when the object appears darker, the reverse is true. When both the object and the background receive practically the same amount of light, the difference in the amount of light reflected by the object and by the background determines whether or not the object can be seen. With a very bright illumination, such as daylight, a small degree of contrast between the object and the background would be sufficient to make it visible but with a low illumination a greater degree of contrast is necessary.

It is for this reason that it is difficult to see a man in dark clothing against a dark background, such as the ground or a dark colored building, when the illumination is low. When such a condition is encountered, and it is not possible to increase the illumination materially it is sometimes possible, by making the background lighter, to cause the object to stand out against it. For instance, in the case of an alley between buildings which has a dark colored building at one end, painting this building white would cause a man in the alley to stand out quite clearly when he might otherwise be almost invisible.

Industrial Controllers-XVIII

Hydraulic Pumps

H. D. James

THERE ARE TWO TYPES of hydraulic pumps in general use, one known as the centrifugal type and the other as the positive acting type. Positive acting pumps are usually of the piston or plunger design.

CENTRIFUGAL PUMPS

A centrifugal pump consists of a rotating set of vanes known as the "impeller," located within a water-tight housing. The water enters at the center of the impeller and is discharged from the periphery. The pressure of the water depends upon the revolutions per minute and the diameter of the impeller. The high head centrifugal pump was not a success with the ordinary type of reciprocating engine; it is, however, particularly well adapted for steam turbine and electric motor drive. Large outputs can be obtained from a relatively small pump, on account of the high speed of operation. The high speed also reduces the weight of the motor for a given horse-power output. The flow of water is continuous, eliminating pulsations which are often objectionable. The amount of water pumped and also the work done by the motor decreases as the head increases. After a certain maximum horse-power is reached, the power decreases with the head.

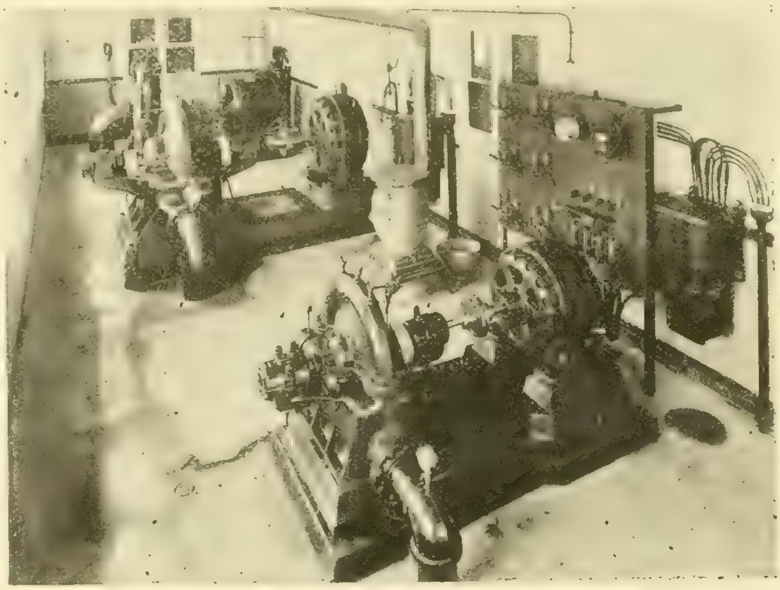

FIG. 1 TYPICAL MUNICIPAL PUMPING PLANT

The pump in the foreground is driven by a 50 hp motor and has a capacity of 1 000 000 gallons per day at 150 feet head. The middle pump is driven by a 75 hp motor and has a capacity of 4 500 000 gallons per day at 60 foot head. The pump in the background is driven by a 100 hp motor and has a capacity of 4 500 000 gallons per day at 60 foot head. The motor starters and feeder panels are shown in the background.

POSITIVE ACTING PUMPS

These pumps consist of a cylinder with either a piston or a plunger. A given amount of water is pumped for each stroke of the piston or plunger. The total volume of water is therefore proportional to the number of strokes of the pump. These pumps are well adapted for the ordinary reciprocating steam engine. When pumps of this type are driven by an electric motor, it is necessary to gear the motor to a crank shaft in order to convert the rotating motion of the motor into the reciprocating motion of the pump. This type of pump is well adapted for high pressure work, but is being largely displaced by the centrifugal pump for ordinary use.

When a positive acting pump is connected to a long discharge pipe considerable work is done in accelerating this column of water from rest to the proper velocity. The effect is somewhat similar to a heavy flywheel on the motor shaft. In applications of this kind, care should be taken to provide a controller of sufficient capacity for accelerating a load with this large amount of inertia.

Small pumps of both kinds are in general use. Many sizes and types can be seen in ordinary hotel or office buildings, and often in private houses. They are used to pump drinking water and for the sanitary system. Some pumps are used where the basement level is below the natural drainage level; requiring the drainage water to be lifted before it can be delivered to the sewage system. Larger pump installations may be found in industrial plants, towns and cities for supplying the water required for these establishments or communities. Many of these pumps are now driven by electric motors.

Central station service is replacing many of the isolated power plants in buildings and industrial establishments. The advantage of a central station supply of electric power is obvious. The cost of this power is usually less and most of the space occupied by the private power plant can be used for other purposes. This general use of central station power is increasing the number of electrically-driven pumps. Where pumping is done on a large scale, arrangements can often be made to do this pumping at the "off peak" time, in this way using the central station equipment to better advantage and exceptionally low rates may be obtained. This utilization of off peak power is very attractive to the central station and is well worth considering by any-

one intending to pump water on a large scale. Even where the pumping must be continuous throughout the twenty-four hours, the power requirements are fairly uniform and good rates can be obtained on account of this uniformity of demand.

SYSTEMS OF CONTROL

Small pumps, driven by squirrel cage motors can be started by connecting the motor directly to the line. Only a primary switch is required. Larger motors may use an autostarter where they are started and stopped infrequently. For frequent starting and stopping, a slip ring motor or a compound direct-current motor should be used. For direct-current service, the compound-wound motor gives the best results for either centrifugal or plunger pumps. For the two latter types of motors, an ordinary non-reversing rheostatic control is used consisting of a line switch for connecting the

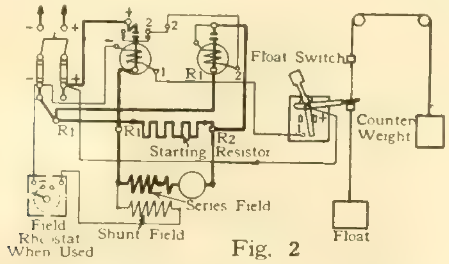

Fig. 2

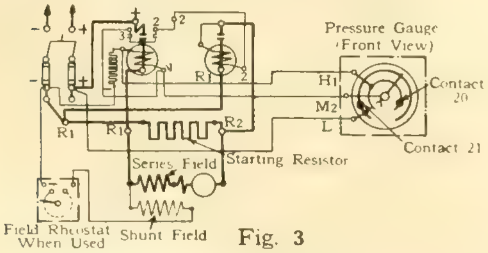

Fig. 3

FIG. 2—CONNECTIONS OF A TWO-POINT DIRECT-CURRENT AUTOMATIC CONTROLLER, OPERATED BY A FLOAT SWITCH

FIG. 3—CONNECTIONS OF A TWO-POINT DIRECT-CURRENT AUTOMATIC CONTROLLER OPERATED BY A PRESSURE GAGE

motor to the circuit, and one or more contactors for short-circuiting the starting resistor. The line switch is usually provided with an overload relay or, if the control is manually operated, the line switch may be an ordinary circuit breaker. A low voltage release is usually supplied with automatic control, as it is desirable to have the motor started automatically upon re-establishment of the power circuit after an interruption. The master switch may consist of a push button or, where speed regulation is desirable, a drum-type master switch can be used. It is usual, however, to start and stop pumps automatically. The automatic means may be actuated by pressure or by the height of the water in the reservoir or tank; the latter is known as a "float switch."

PRESSURE REGULATORS

Two general forms of pressure regulators are used, the "Bourdon gage" and the "diaphragm type." The gage type consists of the ordinary indicating pressure gage with a contact make-and-break device attached to the indicating needle, Fig. 5. Some modifications in the standard gage are required for the addition of this contact device. In order to reduce the arcing at the contact points, a relay is used. This relay is connected so that, when it closes, it bridges the low pressure contact on the pressure gage and prevents an arc at this contact when the gage needle moves to a higher pres-

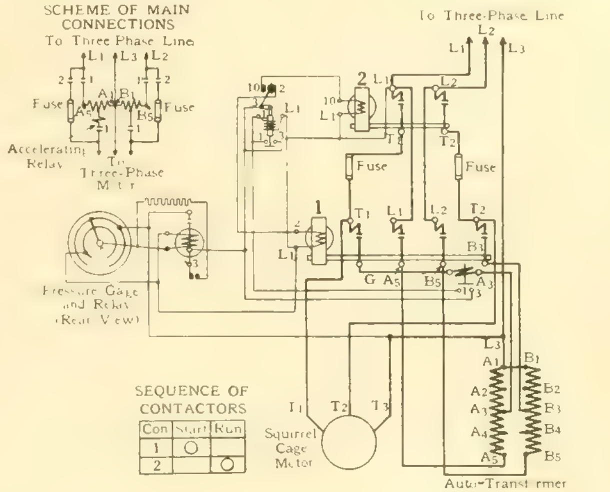

FIG. 4—DIAGRAM OF CONNECTIONS OF AN AUTOMATIC AUTOSTARTER
For a squirrel-cage motor operated by a pressure gage.

sure. The high-pressure contact is arranged for short-circuiting the coil of this relay, which immediately opens the relay, and at the same time opens the circuit through the gage contact. By placing the resistance in series with the relay coil, this short-circuiting can take place without danger of excessive current.

The diaphragm regulator consists of a metal diaphragm having pressure on one side and a weight or spring on the opposite side. The diaphragm raises or lowers, due to variations in the water pressure. This movement of the diaphragm mechanism closes or opens the contacts of the master switch. The diaphragm regulator ordinarily does not require a

FIG. 5—GAGE TYPE PRESSURE REGULATOR

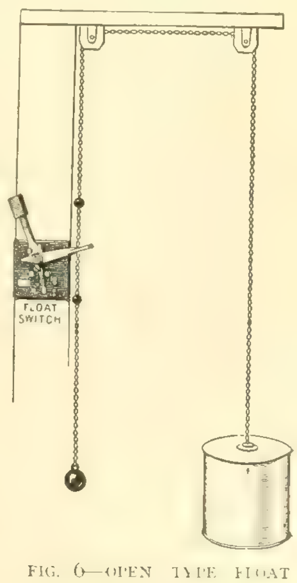

FIG. 6—OPEN TYPE FLOAT SWITCH

the control circuit of an average size contactor.

When a pressure regulator is used with a positive acting pump, it should not be connected directly to the pump delivery as the pulsations cause the regulator to open and close the contacts in rapid succession and give very poor results. Usually the pump delivers to a pres-
relay, as the contacts are large enough to take care of

sure tank or standpipe, and the pressure regulator can be connected to the tank or standpipe. Where the pump delivery is long and it is not convenient to connect the pressure regulator, in this way, special precautions should be taken to prevent the regulator from being oscillated by the pulsation in the pump delivery.

FLOAT SWITCH

This master switch consists of a small contact which is opened or closed due to a difference in level of the water in the tank or reservoir. One form of this switch is shown in Fig. 6. The contacts are provided with a quick make-and-break arrangement so that the slow movement of the float does not cause arcing. This float switch is connected to the pilot wiring of the controller and serves to start and stop the motor, due to variation in the water level. If this float switch is used in a reservoir where large waves are apt to occur, it should be mounted in an enclosed compartment to protect it from the wash.

SPECIAL APPLICATIONS

The foregoing statements are general and in the main, apply to small installations. Larger installations and special applications should be given particular consideration in order to obtain good results.

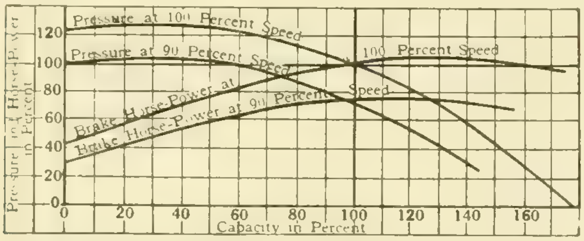

FIG. 7—TYPICAL CAPACITY AND HORSE-POWER CURVES OF A CENTRIFUGAL PUMP

Showing the effect of a ten percent speed variation.

ELEVATOR PUMPS

Among the special applications may be mentioned elevator service. Hydraulic elevators are usually operated in banks comprising several elevators connected to a single pressure tank. The elevators discharge into an open tank and the pump takes the water from the open tank and delivers it to the pressure tank. For large installations, several pumps are used. The pumps are controlled by pressure regulators which start and stop the pump for variations in pressure. During some portions of the day, the pump is operated at infrequent intervals, as the elevator service is light. At other times, particularly the noon hour and closing hour in the evening, office building elevator pumps are started and stopped quite frequently, sometimes two or three times a minute. One method of overcoming this difficulty is to slow the pump down, rather than to stop it when the pressure reaches a predetermined value. If a positive acting pump is used, considerable power may be lost by such an arrangement, as the water pumped is directly proportional to the speed of the pump. To reduce the output one-half, the pump must operate at half speed, which causes a loss in resistance equal to half the electric power delivered to the motor. If centrifugal pumps are used and designed for this service, a small change in speed will make a large change in water delivery. The curves, Fig. 7 represent the gallons of water delivered by a typical pump with reference to the speed of the pump. This shows that a small reduction in speed makes a large difference in the output, and that therefore, by inserting a small amount of resistance in the motor circuit, the output of the pump can be materially decreased with only a small loss in the resistance. Assuming a ten percent reduction in speed, only ten percent of the input of the motor will be wasted as heat in the resistance. The horse-power curves show

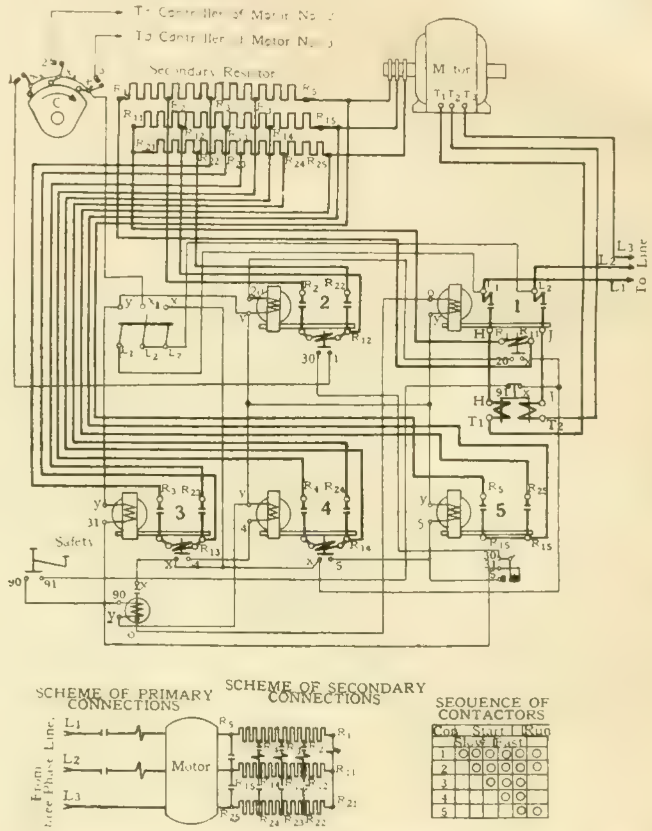

FIG. 8—CONNECTIONS OF A WOUND-SECONDARY INDUCTION MOTOR FOR A LARGE ELEVATOR INSTALLATION

On closing the knife switches in the control circuits of the three motors, switches *1* and *2* on each panel operate in succession, starting up the motors and accelerating them to somewhat less than full speed. If the pressure is low, contacts X_1 on the regulator *C* (shown in detail in Fig. 9) are automatically closed, accelerating motor No. 1 to full speed and then, if needed to maintain the pressure, No. 2 and No. 3 in succession. If the pressure gets too high, motor No. 3 is slowed down and if the pressure still stays high, motors No. 2 and 1 are then decelerated by the regulator. It is necessary to keep all the motors running all the time that the discharge valves are open, in order to maintain pressure on the centrifugal pumps.

a material reduction in horse-power input with a ten percent reduction in speed, so that the loss represents considerably less than ten percent of the full-load input of the motor. The curves showing the relation in percentage between the pressure and gallons of water delivered, indicate that at a small increase in pressure above normal the pump ceases to deliver water. If, however, the pressure drops below normal, the amount of water delivered materially increases. This feature of the centrifugal pump tends to make it self-regulating.

Fig. 8 shows a connection diagram and Fig. 9 the regulator used with three slip-ring motors for a large elevator installation. The regulator varies the speed of the motors, one after another, as the pressure varies.

Municipal Plants— Motor-driven centrifugal pumps* are with considerable success used for pumping the service water for municipalities where central station power is available. Two systems are used—1—Reservoir system, 2—Direct pumping into the service mains. Where the reservoir capacity is sufficient, the pumps may be worked during the night using power at the "off peak" time, thus securing exceptionally good rates and providing a very attractive load for the central station. Usually the water is delivered at 60 to 100 lbs. pressure for ordinary purposes. In the event of a fire, additional pumps are connected in series with the existing pumps to increase the pressure to 100 or 200 lbs. in a restricted district. Some municipalities have a separate set of mains for fire purposes, and electrically operated fire pumps maintain a constant pressure on these mains by means of automatic regulators.

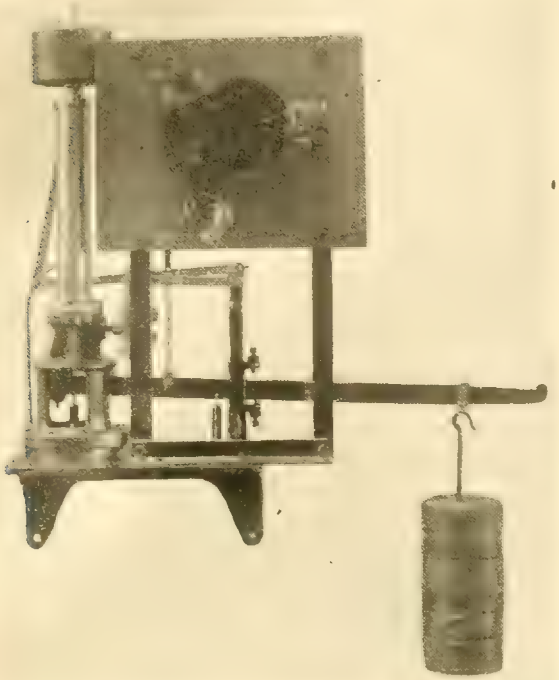

FIG. 9—DIAPHRAGM PRESSURE REGULATOR

For controlling three motors. This regulator consists of a diaphragm balanced by weights to operate at the proper pressure. The diaphragm actuates a pilot valve which admits pressure to the vertical cylinder or connects the vertical cylinder to the discharge mains, depending upon whether the pressure is high or low. The movement of the piston in this vertical cylinder operates a cam which opens and closes the electrical contacts by means of small cam switches. The position of these cam switches is adjustable so that three pumps can be arranged to be started or accelerated in succession as the pressure falls, and to be disconnected or slowed down as the pressure rises.

Where the water is pumped directly into the service mains without reservoir capacity, the centrifugal pump can be designed with a flat delivery curve, so that it automatically regulates the volume of water, depending upon the demand. This can be seen by referring to Fig. 7. With the motor operating at a constant speed the water delivery varies from zero gallons at the maximum pressure to considerably more than the full output of the pump at reduced pressures. If judgement is used in connecting in the proper number of pumps, pressure can be maintained close to the average value and the pumps operated with fair economy.

The argument is often raised that the turbine-driven centrifugal pump will give greater efficiency for varying amounts of water delivered, as the speed can be automatically controlled by a regulator. While this statement is true, it must be remembered that the losses in the steam generating plant are considerable when only a small amount of power is used. The stand-by losses in piping and other equipment forms quite an item of the total loss. A steam generating equipment, consisting of boilers together with the auxiliary equipment required for operating them, represents considerable initial cost and requires the services of several experienced men, whereas a single engineer and attendant are sufficient to operate a large electrically-driven installation.

Where steam power is already installed and used for other purposes, steam driven centrifugal pumps may prove advantageous. On the other hand, if central station power is available at a reasonable rate, the first cost and the maintenance of electrically-driven pumps will be much less than for corresponding steam driven pumps with other boiler house equipment. It is therefore evident that the electrically-driven pump has a considerable field of application for municipal pumping.

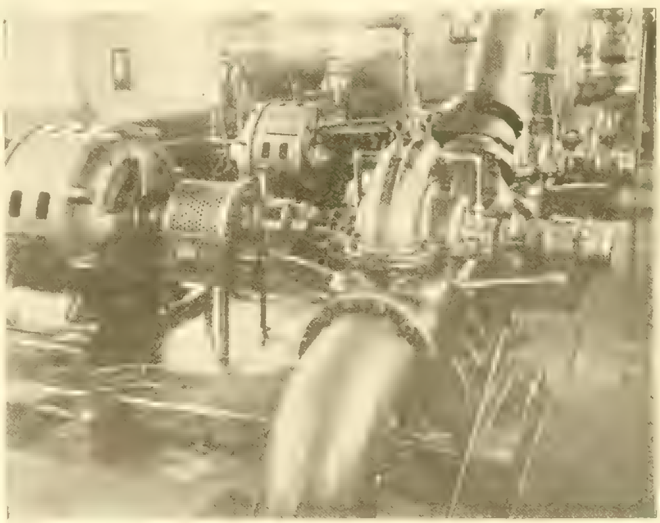

FIG. 10—TYPICAL MOTOR-OPERATED CENTRIFUGAL PUMPS

The motors are rated at 150 hp, 2200 volts and the pumps have a capacity of 3000 gallons per minute at 115 foot head.

In addition to the supplying of service water, electrically-driven pumps are often necessary to provide for a suitable drainage system. These pumps are installed in sump basins located at convenient points in the drainage area. On account of the scattered location of these pumps, electric power is used. A float switch can be

*See article by Mr. R. L. Yates, *Electric Review*, March 16 and 23, 1918, which discusses the hydraulic problem in considerable detail.

arranged to start and stop these pumps with a given variation of level in the sump pits.

Irrigation—The electrically-driven pump is the only solution for pumping water for irrigation purposes. Irrigating pumps must be located at various points scattered over a wide area. Power is usually transmitted at high voltage to suitable substations which supply pumps for a given area. In certain sections of the country the water is obtained from wells, each property owner operating one or more pumps. The limitation to this method of distribution is the expense of changing from the high voltage transmission lines to a low enough voltage to operate the small pump motors. Where this difference in potential is very great, the expense of a stepdown equipment is a considerable item. By combining the substations, the cost of this stepdown equipment can often be materially reduced. This limitation in stepdown equipment is one of the difficulties now experienced by power transmission companies in supplying electric power to farmers and other small users adjacent to their transmission lines.

SUMMARY

Electrically-driven pumps are usually of the centrifugal type and operated at comparatively low pressures, although centrifugal pumps can be built for several hundred pounds pressure when necessary. The use of central station power reduces the first cost and space requirements for such an installation. The operating costs also are reduced, as one attendant can often maintain several pumping stations where automatic control is used. Where pumps are scattered over a considerable area, electric drive is the only solution, as it would be out of the question to distribute steam power to scattered pumps. Where steam power is available, such as in boiler rooms, the feed pumps have been usually operated by steam. Centrifugal pumps, driven by electric motors, are well adapted for large pumping installations, such as are used by municipalities and large industrial works. Where hydroelectric power is available, electric service for pumping during the "off peak" period is usually much cheaper than steam power.

NOTE—Acknowledgement is due to Messrs. H. H. Henderson and E. C. Wayne, Pittsburgh representatives of the Goulds Mfg. Company, for assistance rendered in the preparation of this section.

The Engineering Evolution of Electrical Apparatus-XXIX

The Technical Story of the Frequencies

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THE STORY of how and why the various commercial frequencies came into use and then dropped out is not primarily the story of the frequencies themselves, but of the various uses to which the alternating current has been applied. Some of the applications which have had a determining factor on the frequency of the supply system are incandescent lighting, transformers, transmission systems, arc lighting, induction motors, synchronous converters, constructional conditions in rotating machinery, and operating conditions. Consideration of these items individually indicates that while some of them had very considerable influence, at one time, in determining frequency conditions yet, in a number of cases, the original reasons have disappeared through improvements and refinements. In the following article the various frequencies are considered more or less in the order of their development and basic reasons will be given for their choice, and why certain of them have persisted, while others have dropped out.

AT VARIOUS TIMES the following standard frequencies have been in use in this country, 133 1-3, 125, 83 1-3, 66 2-3, 60, 50, 40, 30 and 25 cycles per second. These did not appear chronologically in the order given above, and a few odd frequencies in a few special applications are omitted.

133 AND 125 CYCLES

In the earliest alternating work, the whole service consisted of incandescent lighting, and the electric equipment was made up of small high-speed belted single-phase generators and house-to-house distributing transformers. It was believed that a relatively high frequency would best meet the transformer conditions. A choice of such an odd frequency as 133 1-3 cycles per second, is due to the fact that in those days (1886 to 1893) frequencies were designated in terms of alternations per minute. One of the earliest generating units constructed by the Westinghouse company had a speed of 2000 r.p.m. and had eight poles. This presented a fairly convenient constructional arrangement for the surface-wound type of rotating armature. This speed gave 16 000 alternations per minute, or 133 1-3 cycles per second according to our present method of designation. Thus the earliest frequency in commercial use in this country was fixed by constructional reasons, although the house-to-house transformer problem apparently indicated the need for a relatively high frequency. The Thomson-Houston company adopted a frequency of 15 000 alternations per minute, (125 cycles) instead of the Westinghouse 16 000, but the writer does not know why this difference was made. However, the two frequencies were so close together that practically they could be classified as one.

At this time there were no real transmission problems, no alternating-current arc lighting, no induction motors and the need for uniform rotation of generators was not recognized. The induction motor came in 1888 and considerable work was done on it in 1889 and 1890, but it required polyphase supply circuits and comparatively low frequency and, therefore, it had no connection whatever with the then standard single-phase,

133 1-3 and 125 cycle systems. The synchronous converter was also unheard of (one might say almost undreamed of) at that time.

60 CYCLES

In 1889 or 1890 it was beginning to be recognized that some lower frequency than 125 and 133 1-3 cycles would be desirable. Also direct-coupled and engine-type alternators were being considered in Europe and it was felt that such construction would eventually come into use in America. In such case, 133 1-3 cycles would present very considerable difficulties compared with some lower frequency, due to the large number of poles which would be required. For instance, an alternator direct driven by an 80 r.p.m. engine would require 200 poles to give the required frequency and such construction was looked upon as being practically prohibitive. About this time Mr. L. B. Stillwell, then with the Westinghouse company, made a careful study of this matter of a new frequency and, after analyzing a number of cases, it appeared that 7200 alternations per minute (60 cycles per second), was about as high as would be desirable for the engine speeds then in sight. Transformer construction and arc lighting were also considered in this analysis. While a somewhat higher frequency might be better for transformers, yet a lower frequency was considered as possibly better for engine-type generators. A compromise eventually led to 60 cycles. While this frequency originated about 1890, it did not come into use suddenly, for it was impossible to introduce such a radical change in a brief time. Moreover, the engine-type generator was slow in coming into general use and, therefore, there was not the necessity for the introduction of this low frequency in many of the equipments sold from 1890 to 1892, However, by 1893, 60 cycles became pretty firmly established and was sharing the business with the 133 1-3-cycle systems. At this time, the adoption of this frequency was not considered as a direct means for bringing forward the polyphase induction motor, for the earlier 60 cycle systems, like the 125 and 133 1-3 cycle, were all single phase. Also, it was thought that the polyphase motor might require a still lower frequency and, moreover, the polyphase system was looked upon as in a class by itself, suitable only for induction motor work. At that time the introduction of polyphase generators for general service was not contemplated. This followed two or three years later.

In 1890 the Westinghouse company, which had been developing the Tesla polyphase motor, laid aside the work, largely because there were no suitable general supply systems for this type of motor. The problem was revived in 1892, in an experimental way, with a view to bringing out an induction motor which could be applied on standard frequencies such as used in commercial supply circuits for lighting and other purposes. At this time such circuits were not in existence but were being contemplated. In 1893, after the polyphase motor had been further developed, the best means for getting it on the market were considered. It was decided that the best way to promote the induction motor business was to create a demand for it on commercial alternating-current systems. This meant that such systems must be created. Therefore, it was decided to undertake to fill the country with polyphase generating systems, which were primarily to be used for the usual lighting service. It was thought that, with such systems available, the time would soon come when there would be a call for induction motors. In this way experience would be obtained in the construction and operation of polyphase generators and the operating public would not be unduly handicapped in the use of such generators, compared with the older single-phase types.

An example of this new practice was in the 2000 kw polyphase generating units used for lighting the Chicago World's Fair in 1893. Here the single-phase type still persisted, as each generator unit was made up of two similar frames placed side by side, but with their single-phase armatures displaced one-half pole pitch from each other so that the combined machine delivered two single-phase currents displaced 90 degrees from each other. It was considered that each circuit could be regulated independently for lighting service, and polyphase motors could be operated from the two circuits. These 60 cycle generators (at that time the largest in this country) were designed in 1892.

25 CYCLES

At the same time that 60 cycles was selected as standard it was recognized that, at some future time, there would be a place for some much lower frequency, but it was not until two years later that this began to narrow down to any particular frequency. In 1892 the first Niagara electrification had centered on polyphase alternating current as the most desirable system. The engineers of the promoting company had also worked out what they considered the most suitable construction of machine. This involved 5000 hp units at 250 r.p.m. Prof. George Forbes, one of the engineers of the company had furnished the electrical designs for a machine with an external rotating field and an internal stationary armature. He used eight poles, thus giving 2000 alternations per minute, or 16 2-3 cycles per second. Quite independently of this, the Westinghouse company, in 1892, had been working on the development of synchronous converters, using belted 550 volt direct-current generators with two-phase collector rings added. The tests on these machines had shown the practicability of such conversion and had proved at this early date, that the converter copper losses were much lower than in the corresponding direct-current generators. The writer, from an analysis of the tests which were made under his immediate direction, concluded that the armature copper losses must be considerably lower than in the same machine used as a direct-current generator. He also brought the matter to the attention of Mr. R. D. Mershon, then with the Westinghouse company, and the problem was then worked out mathematically by him and the writer, in two quite different ways, but with similar results,

showing that the converter actually did have very much reduced copper losses.

As a result of this work of the Westinghouse company on the synchronous converter, it was decided that, to make such machines practicable, some suitable relatively low frequency was required. This appeared to be about 30 cycles. About this time the construction of the Niagara generators was taken up with the Westinghouse company to see whether it would construct these machines according to the designs submitted by the promoting company's engineers. These designs were gone over carefully, and many apparent defects and difficulties were pointed out. The Westinghouse company then proposed a 16-pole, 250 r.p.m. machine. This gave 33 1-3 cycles or as near to the proposed 30 cycle system, as it was possible to get. Many arguments were brought forward for the two machines and frequencies. Prof. Forbes' preference for 16 2-3 cycles was based partly on the possibilities it presented for the construction and operation of commutator type motors. The Westinghouse contention was that this frequency was too low for any kind of service except commutator-type machines. Tests were made with incandescent lights and it was found that at 33 1-3 cycles there was little or no winking of light, while at 16 2-3 cycles, the winking was extremely bad. Tables were also made up, showing the limited number of speed combinations at 16 2-3 cycles for induction motors, in case such should come into use. Those showed how superior the 33 1-3 cycles would be as regards such apparatus. It was also brought out that synchronous converters would be much better adapted for the higher frequency, as the choice of speeds would be much greater. From the present viewpoint the arguments appear to have been much in favor of the Westinghouse side of the case.

As a consequence of all this discussion, the suggestion was advanced that a 12 pole, 250 r. p.m. machine (that is, 3000 alternations, or 25 cycles) might meet sufficiently the good qualities of both of the proposed frequencies and would be a good compromise. In consequence a 12 pole, 25 cycle design was worked up by Westinghouse engineers and eventually this frequency was adopted for the Niagara generators. Afterwards, while these generators were being constructed it was brought out pretty strongly that the great advantage of this frequency would be in connection with synchronous converter operation, but that it was also extremely well adapted for slow-speed engine-type generators. In consequence of the prominence given this frequency it was soon adopted as a standard low frequency, especially in those plants where synchronous converters were expected to form a prominent part of the system.

However, while 60 and 25 cycles came into use, it must be recognized that they had competitors. For instance, 66 2-3 cycles (8000 alternations or one-half of 16 000) were used to a considerable extent by one manufacturing company. Also 50 cycles came into use in certain plants and, to a certain extent, is still retained. A brief attempt was made later to place 40 cycles upon the market as a substitute for both 25 and 60 cycles. This was done under the impression that 40 cycles would give a universal system for arc and incandescent lighting, transmission, induction motors, synchronous converters and about everything else. This frequency possessed many merits and it was thought, at one time, that it might win out, but apparently the other two frequencies were too well established, and the 40 cycle system eventually lost ground.

The problem of the frequencies finally narrowed down to the two standards, and these two were accepted because it was thought that they covered such entirely different fields of service that neither of them could ever expect to cover the whole. In other words, two standards were required to cover the whole range of service. It was recognized that 25 cycles would not take care of alternating-current arc lighting and that it was questionable for incandescent lighting in general. In other ways, such as suitability for engine-type construction, application to induction motors and synchronous converters and transmission of power to long distances, it met the needs of an ideal system, as then understood. Also, in parallel operation of engine-type alternators, which was one of the serious problems of those days, the 25 cycle machines were unquestionably superior to the 60 cycle ones., due to the lesser displacement of the e.m.f. waves with respect to each other with a given angular variation in the engine speeds. However, although the 25 cycle system presented so many advantages, it could not take care of the lighting business, and, therefore, could not entirely dominate the situation.

As regards 60 cycles, it was felt that this could handle the direct lighting situation in a very satisfactory manner and was possibly better suited for transformers than 25 cycles. It was reasonably well adapted for induction motors in general, but not for very low speeds.

The 25 cycle system presented the stronger showing and there was a decided tendency toward this frequency, except in those cases where lighting directly from the alternating-current system was considered of prime importance. In systems where low-voltage three-wire direct current was used from synchronous converters, the tendency was toward the 25 cycle system. In those days the central station which had gotten itself committed to the 60 cycle system so deeply that it could not change, was looked upon with commiseration. In fact, so strong was the tendency toward 25 cycles that, in many cases, 25 cycle plants were installed for industrial purposes, where 60 cycles would have been better. The 25 cycle synchronous converter development advanced by leaps and bounds and the machines operated so well that it was believed that 60 cycle converters could never be really competitive with them.

On the other hand, in those large plants which were so "unfortunate" as to have 60 cycles installed, many apparent makeshifts were adopted to meet the various service requirements.There were many who advocated motor-generators for this purpose, largely because the 60 cycle converter was thought to be impracticable.

Low-speed engine-type 60 cycle generators were not always adapted for operation of synchronous converters. In numerous cases, such generators would not operate in satisfactory manner in parallel with each other, and yet when synchronous converters were operated from these same generators the unsatisfactory results were not blamed upon the generating system but upon the converters. Unfortunately, defects in the generating and transmission systems usually appeared in the converters as sparking and flashing, and such troubles naturally would be credited to defects in the construction of the converters themselves. In fact, in those days, 60 cycle converters were expected to do things which now are considered as absurd. For instance, in one case a 60 cycle synchronous converter was criticized as being very badly designed, due to serious flashing at times. Investigation developed that this converter was expected to operate on either one of two independent 60 cycle systems with no rigid frequency relation to each other. The converter in service was switched from one system to the other indiscriminately, and sometimes it flashed in the transfer and sometimes it did not.

At one time the writer stood almost alone in his belief that the 60 cycle synchronous converter presented commercial possibilities sufficient to make it a strong future contender with the 25 cycle machine, provided proper supply conditions were furnished and certain difficulties in the proportions of the converter were overcome. One basis for his contention was that in some of the 60 cycle plants, where the generator rotation was quite uniform, the converters were much superior in their operation to those in other plants, using slow-speed engine-type generators with considerable periodic variations. In such plants the hunting tendency of the converters was greatly reduced, with consequent improvement in sparking and general operation. It was early recognized that hunting was a very harmful condition, both in 60 and 25 cycle converters, but whereas it was relatively rare in 25 cycle plants it was much more common with 60 cycles. However, the operating public was not particularly concerned whether the trouble was in the generating plant or in the converters themselves, as long as such trouble existed and was not overcome. Early in synchronous converter development it was found that hunting produced sparking or flashing at the commutators. However, even in those plants where there was no hunting apparent, there was difficulty at times due to flashing, especially with sudden change of load, which resulted in temporary increase in the direct-current voltage. This was a difficulty which was inherent in the converter itself and could not be blamed entirely upon the generating or transmitting conditions, for 25 cycle machines were practically free from this trouble under similar conditions of operation. Investigation developed the fact that this flashing trouble was due largely to the unduly high value of the maximum volts between commutator bars. This difficulty was recognized long before it was overcome, simply because certain physical limitations in construction had to be removed. There were two ways in which the maximum volts per bar could be reduced—by increasing the number of commutator bars per pole and by decreasing the ratio of the maximum volts to the average volts per bar, that is, by increasing the ratio of the pole width to the pole pitch, but both of these involved structural limitations in the allowable peripheral speeds of the commutator and the armature core.

Here is where a little elementary mathematics comes in. The peripheral speed of the commutator is directly proportional to the distance between adjacent neutral points on the commutator, and the frequency. Therefore, with a given frequency the distance between the adjacent neutral points is directly proportional to the peripheral speed. Thus, with a commutator speed of 4500 ft. per min. which was then considered an upper limit, the distance between adjacent neutral points on a 60 cycle converter is only 7.5 in. This distance is thus fixed mathematically and is independent of the number of poles or speed, or anything else, except the peripheral speed and the frequency. With this distance of 7.5 in. about the only choice in commutator bars per pole was 36, giving an average of 16 2-3 volts per bar on a 600 volt machine, and nearly 20 volts per bar with momentary increase of voltage to 700, which is not uncommon in railway service.

However, it is not this average voltage which fixes the flashing conditions, but the maximum voltage between bars, and this is dependent upon the average voltage and upon the ratio of the pole width to the pole pitch. As the pole pitch is directly dependent upon the peripheral speed of the armature and the frequency, therefore, if the peripheral speed is fixed, the pole pitch is at once fixed. For example, with an armature peripheral speed of 7200 ft. per min., which was considered high at that time, the pole pitch becomes 12 in., and here was where a most serious difficulty was encountered. If a sufficiently wide neutral zone for commutation was allowed the interpolar space became so wide that there was not enough left for a good pole width. For instance, if the interpolar space was made 6 in. wide, in order to give a sufficiently wide commutating zone to prevent sparking or flashing, due to fringing of the main field, then this left only 6 in. for the pole face. With this relatively narrow pole face the ratio of the maximum to average volts was so high that with the 36 commutator bars per pole the machine was so sensitive to arcing between commutator bars that flashing resulted. By widening the pole face this difficulty would be lessened or overcome, but with the fixed pole pitch of 12 in. the neutral zone would be so narrowed as to make the machine sensitive to sparking and flashing at the brushes. Thus, no matter which way we turned trouble was encountered. Obviously there were two directions of improvement, namely, by increasing the number of commutator bars, thus reducing the average voltage, and by increasing the pole pitch, thus allowing relatively wider poles with a given interpolar space. These two conditions look simple and easy, but it took several years of experience to attain them. When we

have reached apparent physical limitations in a given construction, especially when such limitations are based upon long experience, we have to feel our way quite slowly toward higher limitations. For instance, in the case of the 60 cycle converters we could not boldly jump our peripheral speeds 20 to 25 percent higher and simply assume that everything was all right. We first had to build apparatus and try it out for a year or so. Troubles, due to peripheral speed, do not always become apparent at once, and time tests are necessary. Therefore, while the peripheral speeds of the 60 cycle synchronous converters were actually increased 20 to 25 percent, yet it took two or three years of experimentation and endurance tests before the manufacturers felt sure enough to adopt the higher speeds on a broad commercial scale. Thus, while the change from the older more sensitive type of 60 cycle converter to the later type occurred commercially within a comparatively short period, the actual development covered a much longer period.

As regards the commutator, the number of bars could be increased 25 percent, that is, from 36 to 45 per pole, which was comparable with ordinary direct-current generator practice. In the second place, an increase of 25 percent in the peripheral speed of the armature core meant a 15 in. pole pitch, where 12 in. was used before. Assuming, as before, a 6-in. interpolar space, then the pole face itself became 9 in. in width instead of 6 in., an improvement of 50 percent. In fact, this latter improvement was so great that some manufacturers did not consider it necessary to increase the number of commutator bars, although in the Westinghouse machines both steps were made.

These improvements so modified the 60 cycle converter that it began to approach the 25 cycle machine in its general characteristics. It was still quite expensive compared with the 25 cycle, due to the large number of poles, and its efficiency was considerably lower, on account of high iron and windage losses. However, due to the need for such a machine it was gradually making headway, in spite of handicaps in cost and efficiency.

Almost coincident with the initiation of improvements in the 60 cycle converter, came another factor which has had much to do with the success of this type of machine. This was the advent of the turbogenerator. As stated before, one of the handicaps of the 60 cycle converter was in the non-uniform rotation of the engine-type generators which were common in the period from 1897 to about 1903 or 1904. But, about this latter date, the turbo-generator was making considerable inroads on the engine-type field and within a relatively short period it so superseded the former type of unit, that it was recognized as the coming standard for large alternating power service. With the turbogenerator came uniform rotation. However, in the early days of the turbogenerator, 25 cycles still was in the lead and many of the earlier generators were made for this frequency, especially in the larger units. But it was not long before it was recognized that 60 cycles presented considerable advantage in the turbogenerator design due to the higher permissible speeds. In the earlier days of turbogenerator work, this was not recognized to any extent, as the speeds of all units were so low that the effect of any speed limitations was not yet encountered. For instance, a 1500 kw, 60 cycle turbogenerator would be made with six poles for 1200 r.p.m., while a corresponding 25 cycle unit would be made with two poles for 1500 r.p.m. This slightly higher speed at 25 cycles about counterbalanced the difficulties of the two-pole construction compared with the six-pole. However, before long, more experience enabled the six-pole, 60 cycle machine to be replaced at 1800 revolutions, and a little later by two poles at 3600 revolutions. This, of course, turned the scales very much in the other direction. In larger units, however, the advantage still appeared to be in favor of 25 cycles, but in the course of development, 1500 revolutions was adopted quite generally for 25 cycle work, and this was the limiting speed, as such machines had only two poles. On the other hand, for 60 cycles, 1800 revolutions was adopted quite generally for units up to almost the extreme capacities that had been considered, consequently the constructional conditions in the large machines swung in favor of 60 cycles. Therefore, with the coming of the steam turbine and the development of high-speed turbogenerator units, the tendency has been strongly toward 60 cycles. This, with the greater perfection of the 60 cycle converter, had much to do with directing the practice away from the 25 cycles.

However, there were other conditions which tended strongly toward 60 cycles. In the early development of the induction motor, the 25 cycle machines were considerably better than the 60 cycle and possibly little or no more expensive. However, as refinements in design and practice came in, certain important advantages of the 60 cycle began to crop out. For instance, with 25 cycles there is but little choice in speed, for motors of small and moderate size. At this frequency a four-pole motor has a synchronous speed of only 750. The only higher speed permissible is 1500 revolutions with two poles, and it so happens that in induction motors the two-pole construction is not materially cheaper than the four pole, consequently the principal advantage in going to 1500 revolutions was only in getting a higher speed where such was necessary for other reasons than first cost. However, in 60 cycles the case is quite different, where a four pole machine can have a speed of 1800 revolutions, a six pole 1200, an eight pole 900 and a ten pole 720 revolutions. In other words, there are four suitable speed combinations where a 25 cycle motor had only one. Moreover, with the advance in design it developed that these higher speed 60 cycle motors could be made with nearly as good performances as with the 25 cycle motors of same capacity, and at somewhat less cost. However, leaving out the question of cost, the wider choice of speeds alone was enough to give the 60 cycle motor a pronounced preference for general service.

However, there is one exception to the above. Where very low-speed motors are required, such as 110

r.p.m., the 60 cycle induction motor is at a considerable disadvantage compared with 25 cycles. It is partly for this reason that the steel mill industry adopted 25 cycles as standard some ten or fifteen years ago. At that time, it was considered that there would be need for very low-speed motors in many cases. However, due to first cost, as well as other things, there has been a tendency toward much higher speeds in steel mill work, through the use of gears and otherwise, so that part of this argument has been lost. However, there still remain certain classes of work where direct-connected very low-speed induction motors are desirable and where 25 cycles would appear to have a distinct advantage.

In view of these considerations, steel mill work has heretofore gone very largely toward 25 cycles, particularly where the mills installed their own power plants. However, in recent years there has been a pronounced tendency toward purchase of power from central stations, and the previously described tendency of central stations toward 60 cycles has forced the situation somewhat in the steel mills, particularly in those cases where the central power supply company can furnish power at more reasonable rates than the steel mill can produce in its own plant. This, therefore, has meant a tendency toward 60 cycles in steel mill work, even with the handicap of inferior low-speed induction motors. But, on the other hand, remedies have been brought forward even for this condition. The great difficulty in the construction of low-speed, 60 cycle induction motors is in the very large size and cost if constructed for normal power-factors, or the very low power-factor and poor performance if constructed of dimensions and costs comparable with 25 cycles. In the latter case the extra cost is not entirely eliminated because a low power-factor primary input implies additional generating capacity, or some means for correcting power-factor on the primary system.

In some cases it is entirely practicable to correct the power-factor in the motors themselves by the use of so called "phase advancers" of either the Leblanc or the Kapp type. Such machines are connected in the secondary circuits of induction motors and arranged so as to furnish the necessary magnetizing current to the rotor or secondary instead of to the primary. In this way the primary current to the motor will represent largely energy and the power-factors can be made equal to, or even much better than in the corresponding 25 cycle motor; or, in some cases, the conditions may be carried even further so that the motor is purposely designed with a relatively poor power-factor, in order to further reduce the size and cost, and the phase advancers are made correspondingly larger. In those cases where the cost of the phase advancer is relatively small compared with the main motor, there may be a considerable saving in the cost of the main motor which will more than offset the cost of the phase advancer. One difficulty in the use of phase advancers is found in the variable speeds required in some kinds of mill work. In those cases where flywheels driven by the main motors are desirable to take up violent fluctuations in load, it is necessary to have considerable variations in the speed of the induction motor, in order to bring the stored energy of the flywheel into play. Unfortunately this variable speed in the induction motor is one of the most difficult conditions to take care of with a phase advancer, so that here is a condition where the 60 cycle motor is at a decided disadvantage.

Thus it may be seen that even in the steel mill field, where the induction motor has the most extreme applications, there is quite a strong tendency toward 60 cycles, due to the purchase of power from central supply systems.

There remains one more important element which has had something to do with the tendency toward 60 cycles, namely, the transmission problem. In the earlier days of transmission of alternating current, 25 cycles was considered very superior to 60 cycles due to better inherent voltage regulation. However, a number of power companies in the far west installed 60 cycle plants, principally for local service and with the growth of these plants came the necessity for increased distance of transmission through development of water powers. At first it was thought they were badly handicapped by the frequency, but gradually the apparent disadvantages of their systems were overcome and the distances of transmission were extended until it became apparent that they could accomplish practically the same results as with 25 cycles. Part of this result has been obtained by the use of regulating synchronous condensers. It is a curious fact that the possibility of synchronous motors used as condensers for correction of disturbances on transmission systems, has been known for about 25 years, but it is only within quite recent years that they have come into general use as a solution of the transmission problem, and largely in connection with 60 cycle plants. In 1893 the writer applied for a patent on the use of synchronous motors as condensers for controlling the voltage at any point on a transmission system by means of leading or lagging currents in the condenser itself. A broad patent was obtained, but there was no particular use made of it until it had practically expired.

Another improvement, which still further helped to advance 60 cycles to its present position, was the use of commutating poles in synchronous converters. The principal value of commutating poles in the 60 cycle converters, has not been so much in an improvement in commutation over the older types of machines, as in allowing a very considerable reduction in the number of poles with corresponding increase in speed, resulting in reduction in dimensions. As a direct result of this increase in speed the efficiencies of the converters have been increased. If, for instance, the speed of a given 60 cycle converter can be doubled by cutting its number of poles to one-half, while keeping the same pole pitch and the same limiting peripheral speed, then obviously the amount of iron in the armature core is practically halved and, at the same magnetic densities, the iron loss is also practically halved. Also with the same peripheral speed and half diameter of armature, the windage losses can be decreased materially. Thus the two

principal losses in the older converters have been very much reduced. There have also been reductions in the total watts for field excitation and in other parts, so that, as a whole, the efficiency for a given capacity 60 cycle converter has been brought up quite close to that of the corresponding 25 cycle machine, even when the latter is equipped with commutating poles. This gain of the higher frequency compared with the lower is due to the fact that the lower-frequency machine was much more handicapped in its possibilities of speed increase, and furthermore, the iron losses and windage represented a much smaller proportion of the total losses in the low-frequency machine. This improvement in the efficiency of the 60 cycle converter together with the lower losses in the 60 cycle transformer as compared with the 25 cycle, has brought the 60 cycle equipment almost up to the 25 cycle, so that the difference at present is not of controlling importance. This development has given further impetus toward the acceptance of 60 cycles as a general system. Formerly the 60 cycle motor-generator was a serious competitor with the 60 cycle converter. This was installed in many cases because it was considered more reliable and more flexible in operation than the synchronous converter. Both of these claims were true to a certain extent. However, with improvements in the synchronous converter the difference in reliability disappeared, but there remained the difference in flexibility. In the motor-generator set, the direct-current voltage could be varied over quite a wide range, while in the older 60 cycle converters the direct-current voltage held a rigid relation to the alternating supply voltage. However, with the development and perfection of the synchronous booster converter, flexibility in voltage was obtained with relatively small increase in cost and minor loss in economy. This has been the last big step in putting the 60 cycle converter at the front as a conversion apparatus, so that today it stands as the cheapest and most economical method of converting alternating current to direct current. Moreover, while the 25 cycle synchronous converter has apparently reached about its upper limit in speed, there are still possibilities left for the 60 cycle converter.

For units of 1000 kw and less, the 60 cycle converter has nearly driven the 25 cycle out of business from the manufacturing standpoint. For the very large converters, 25 cycles still is used, but largely in connection with railway and three-wire systems, which have been installed for many years; that is, the growth of this business is in connection with existing generating systems. However, the 60 cycle converter, in large capacity units, is gaining ground rapidly and the largest converters yet built, namely, 5800 kw are of the 60 cycle type.

It must not be assumed that because 60 cycles appears to be the future frequency in this country, that 25 cycles was a mistake. In reality it formed a most important step toward the present high development of the electric industry. Many things we are now accomplishing with 60 cycles would possibly never have been brought to present perfection, if the success of the corresponding 25 cycle apparatus had not pointed the way. The success of the 25 cycle converter, and the high standard of operation attained, gave ground for belief that practically equal results were obtainable with 60 cycles. Therefore, the 25 cycle frequency served a vast purpose in electrical development; it was a high class pacemaker, and it isn't entirely out-distanced yet.

There has been considerable speculation as to what two standard frequencies would have met the needs of the service in the best manner, and would have resulted in the greatest development in the end. It has been claimed by some, that 50 and 25 cycles would have been better than 60 and 25. In the earlier days possibly the former would have been better, but as a result both standards might have persisted longer. In any case, the general advantages would have been small. In one class of machines, namely, frequency changers, consisting of two alternators coupled together, the 25-50 combination would certainly have been advantageous.

Again it has been questioned whether 30 and 60 cycles would not have been a better choice. This was the original Westinghouse choice of frequencies. It was felt that 30 cycles could do about all that 25 cycles could, and would give an advantage of 25 percent higher speed in motors and converters, with correspondingly higher capacities. Also for direct-coupled alternators, the two-to-one ratio of frequencies would fit in with engine speeds.

Something further may be said regarding the 40 cycle system brought out by the General Electric Company. This contained many very good features, for the time it was brought out. It was then believed that, if the 60 cycle frequency was retained, the double standard was necessary. The 40 cycle system was an attempt to eliminate this double standard. It apparently furnished a better solution than 60 cycles then promised for the synchronous converter problem, and was a fair compromise in about everything else. But it came too late, for the 25 cycle system was too firmly entrenched, and for further development, the designing engineers preferred to expend their energies in seeing what could be accomplished with 60 cycles, as this seemed to present greater possibilities than either 25 or 40, if it could be sufficiently perfected. Thus the 40 cycle system probably missed success due to being just a little too late.

As to 50 cycles, it was stated that this is still in use to a limited extent. Most of the 50 cycle plants in this country are in California. Such plants were started during the nebulous period of the frequencies, and have persisted, to a certain extent, partly because certain 60 cycle apparatus could be easily modified to meet the 50 cycle requirements. Also, as 50 cycles is the standard in many foreign countries to which this country exports equipment, the use of 50 cycles in some home plants has not been unduly burdensome from the manufacturers' standpoint.

In addition to the preceding, there have been certain classes of electric service which have depended upon frequency, but which have not been a determining

factor in fixing any particular frequency. Among these may be considered commutating types of alternating-current apparatus. The first alternating-current commutating motors of any importance, were the 25 cycle, single-phase railway motors. These as a rule have operated from their own generating plants, or from other plants through frequency-converting machinery. One exception in the railway work is the use of 15 cycles on the Visalia plant in California. There is a pretty well defined opinion among certain engineers experienced in such apparatus that some low frequency, such as 15 cycles, would present very considerable advantages in the use of single-phase railway motors in very heavy service, such as on some of the western mountain roads. Here the problem is to get the largest possible motor capacity on a given locomotive, and the main advantage of the lower frequency would be in allowing a very materially higher capacity within a given space. This does not imply reduced weight or cost compared with the 25 cycles, but simply means greater motor capacity. With the modern, more highly developed, single-phase railway motors, it would appear that there may be very considerable possibilities in 15 cycles.

Outside of the railway field, there has been recently a development of various types of alternating-current commutating apparatus, principally in connection with heavy steel mill electrification work. Such apparatus has been largely in the form of three-phase commutating machines and these have been used principally in connection with speed control of large induction motors. As these regulating machines are usually connected in the secondary circuits of induction motors, the frequency supplied is represented by the slip frequency. Consequently where the slip frequency never rises to a large percentage of that of the primary system, such commutating motors are applicable without undue difficulties. Such motors, presumably are better adapted for 25 cycle mill equipments than for 60 cycle, but due to the tendency, already described, for steel mills to go to 60 cycles on purchased power, it has been necessary to build these three-phase commutating motors for the regulation of 60 cycle main motors, in many cases.

There is still another class of service, which has come in recently, where the choice of frequency is of much importance, but where there is no great necessity for adhering to any standard, namely, in heavy ship propulsion by electric motors. As each ship equipment is a complete system in itself, and as it cannot tie up with other systems, there is no controlling need for maintaining any definite frequency. Except in similar vessels, there is little chance for duplication in parts, as the various equipments vary so much in size and capacity. In consequence it has been found advisable to design each propulsion equipment for that frequency which best suits the generator and motor speeds, taking into account the various operating conditions and limitations, such as the different running speeds, steaming radius, etc. At the present time with the relatively small amount of experience obtained with the electrical propulsion of ships, it looks as if it would be a considerable handicap to attempt to adopt some standard frequency for all service. Later, with wide experience, it may be possible to adopt some compromise frequency, which will not unduly handicap any of the service.

CONCLUSION

As a rule, the choice of frequency has been a matter of most serious consideration, based upon service conditions at the time. Moreover, in view of the wide range of conditions encountered, it is surprising how few frequencies have been seriously considered in this country. Occasion has arisen, times without number, where an obvious solution of a given problem would lie in modification of the frequency to allow the use of apparatus and equipment already designed, but the engineers of the manufacturing organization have steadily held out against such policy, regardless of the apparent need of the moment. The swing of the pendulum from 60 cycles to 25 cycles and back, has covered a period of many years and, therefore, cannot be considered as a fad of the moment, but is the result of well defined tendencies, backed by the best engineering experience available.

The Essentials of Transformer Practice—XI

General Design Relations

E. G. Reed

There are a number of general relations between the factors which enter into the design of a transformer which are of interest and value in showing how its various characteristics are dependent upon one another. These relations, while theoretically correct, are based upon certain assumptions which are only approximately true and for but a limited range of variation. For this reason the equations must be used with caution and with a full knowledge of the limitations imposed, or erroneous results will be secured.

RELATION BETWEEN THE OUTPUT AND DIMENSIONS, WEIGHT AND COST OF A TRANSFORMER

If in equation *2* section *X*, the values of the working densities in the iron and copper, and the space factor in the winding are constant, it is evident that the output P is proportional to $A_0\ A_1$. Since each of these areas is proportional to the product of their dimensions, they are proportional to the square of one of the dimensions of the transformer. If one of the dimensions of

the transformer be represented by b then the product of $A_c A_i$ is proportional to b^4, then,—

$$P \propto b^4 \quad \text{.......................................} \quad (1)$$

or the output of a transformer is proportional to the fourth power of its dimensions.

Example:—If the dimensions of a transformer be increased by 10 percent, what will be the increase in its output rating, assuming that it is not limited by the heating of the windings?

From equation *1* the output of the transformer becomes $(1.1)^4$ or 1.46 times the original rating.

Since the weight and cost of the active material in a transformer increase as the cube of its dimensions, from equation *1* the relations between its output, cost and weight, can be determined, as follows,—

$$P \propto (Weight)^{\frac{4}{3}} \quad \text{...........................} \quad (2)$$

$$P \propto (Cost)^{\frac{4}{3}} \quad \text{...............................} \quad (3)$$

Example:—If the cost and weight of the active material in a transformer be increased by 10 percent, what will be the increase in its output rating?

From equations *2* and *3* the output of the transformer becomes $(1.1)^{\frac{4}{3}}$ or 1.13 times the original rating.

The same rates of increase will apply with some degree of accuracy to the total weights and costs of the transformer, if the ranges of increase or decrease are not large and it is assumed that the same constants of design apply.

Example:—If a 5 k.v.a. transformer weighs 235 pounds, what will be the approximate weight of a 10 k.v.a. unit of similar design?

From equation *2* the weight of the 10 k.v.a. transformer will be approximately $235 \times \left(\frac{10}{5}\right)^{\frac{3}{4}}$ or 305 pounds.

Example:—If the selling price of a 5 k.v.a. transformer is \$73.50, what is the approximate selling price of a 10 k.v.a. unit?

From equation *3* the selling price of the 10 k.v.a. unit will be approximately \$73.50 $\times \left(\frac{10}{5}\right)^{\frac{3}{4}}$ or \$123.50.

RELATION BETWEEN THE OUTPUT AND THE SUM OF THE IRON AND COPPER LOSSES OF A TRANSFORMER

Both the sum of the iron and copper losses of a transformer, as well as its total equivalent loss, may be expressed in terms of its k.v.a. output. The sum of the losses L, may be expressed in terms of the iron and copper loss as follows,—

$$L = L_i + L_c$$
$$\text{or, } L = W_i G_i + W_c G_c$$

The weight of iron and copper G_i and G_c in the transformer, are proportional to the volumes of those elements. Since the volume of an object is proportional to the cube of its dimensions, if b is one of the dimensions of a transformer, the weight of both the iron and copper elements are proportional to b^3. The above equation may thus be written;—

$$L \propto W b^3$$
$$\text{or } L = (W_i + W_c) b^3$$

Assuming that the flux density in the iron and the current in the copper are constant, this relation may be written,—

$$L \propto b^3 \quad \text{.......................................} \quad (4)$$

That is the sum of the losses varies as the cube of the linear dimensions of the transformer. It has been shown in equation *3* that $P \propto b^4$ and since $L \propto b^3$

$$L \propto (P)^{\frac{3}{4}} \quad \text{.................................} \quad (5)$$

This means that with transformers of greater and greater size, using more copper and iron in their coils and magnetic circuits, the output and total loss increase such that the sum of the losses increases as the ¾ power of the output rating.

Example:—If the sum of the losses for a 25 k.v.a. transformer is 570 watts, what will be the approximate sum of the losses for a 50 k.v.a. unit of similar design?

From equation *5* the sum of the losses for the 50 k.v.a. transformer will be approximately $570 \times \left(\frac{50}{25}\right)^{\frac{3}{4}}$ or 958 watts.

If equation *5* be divided through by P, the following expression results, which gives the relation between the total losses for different sizes of transformers in a form more convenient for ordinary use;—

$$\textit{Percentage of total loss} \propto \frac{1}{P^{\frac{1}{4}}} \quad \text{...............} \quad (6)$$

Example:—If the percentage of total loss of a 7.5 k.v.a. transformer is 2.67 percent, what is the approximate percentage of total loss for a 15 k.v.a. unit?

From equation *6* the loss for the 15 k.v.a. transformer would be approximately $2.67 \times \left(\frac{7.5}{15}\right)^{\frac{1}{4}}$ or 2.25 percent.

RELATION BETWEEN THE OUTPUT AND TOTAL EQUIVALENT LOSS OF A TRANSFORMER

Equation *15*, section *IV* may be written, when the frequency is constant, as follows:—

$$W_i^{\frac{1}{y}} W_c^{\frac{1}{2}} \propto \frac{P}{A_i A_c S_c}$$

Multiplying through by $G_i^{\frac{1}{y}} G_c^{\frac{1}{2}}$, where G_i and G_c are the weights of iron and copper respectively, gives,—

$$L_i^{\frac{1}{y}} L_c^{\frac{1}{2}} \propto \frac{P G_i^{\frac{1}{y}} G_c^{\frac{1}{2}}}{A_i A_c S_c}$$

or when y is equal to 2

$$L_i L_c \propto \left(\frac{P G_i^{\frac{1}{2}} G_c^{\frac{1}{2}}}{A_i A_c S_c}\right)^2 \quad \text{.................} \quad (7)$$

This equation shows the relation between the equivalent total loss of the transformer and its output rating. Assuming a transformer of fixed dimensions, working at a definite frequency, the equivalent total loss is proportional to the square of the output rating. That is,—

$$L_i L_c \propto P^2 \quad \text{..............................} \quad (8)$$

Example:—If the product of the losses for a 100 k.v.a. transformer is 6 x 10[5], what is the product of the losses for a 200 k.v.a. unit?

From equation *8* the product of the losses for the 200 k.v.a. transformer will be approximately 6 x 10[5] x $\left(\frac{200}{100}\right)^2$ or 24 x 10[5]. If the ratio of the copper to the iron loss is 2 for the 100 k.v.a. unit it will be the same for the 200 k.v.a. transformer, therefore,—

$$L_i = \sqrt{\frac{24 \times 10^5}{2}} = \textit{1095 Watts.}$$

$$L_c = 2 \times 1095 = \textit{2190 Watts.}$$

Equation *8* may be divided through by P, which gives, $\frac{L_i L_c}{P} \propto P$, or the equivalent total loss expressed as a percentage of the output, is proportional to the output rating or,—

$$\textit{Percentage of equivalent total loss} \propto P \quad \text{.............} \quad (9)$$

This means that if a curve be plotted between the percentage of equivalent total loss and output ratings,

it will be a straight line if the same constants of design be maintained, and the ratio of the copper and iron losses is constant. This relation gives an easy way to determine the losses of a line of transformers, when the losses for two similar designs of different rating are known.

Example:—If the iron and copper losses for a 5 and a 200 k.v.a., 2300 to 230 volt, 60 cycle transformer, are as given in the table below, what are the losses of the other sizes of the line using the same constants of design?

K.V.A.	Watts Iron Loss	Watts Copper Loss by Wattmeter at 75° C.	$\frac{L_i L_c}{P}$
5	45	90	810
200	1120	2240	12500

Plotting the curve between k.v.a. rating and $\frac{L_i L_c}{P}$ gives the straight line shown in Fig. 1. The performance of this line of transformers from this curve would be approximately as follows:

K.V.A.	Watts Iron Loss	Watts Copper Loss by Wattmeter at 75° C.
5	45	90
7.5	61	122
10	74	148
15	99	198
25	158	316
37.5	225	450
50	304	608
75	433	866
100	570	1110
125	710	1420
150	850	1700
200	1120	2240

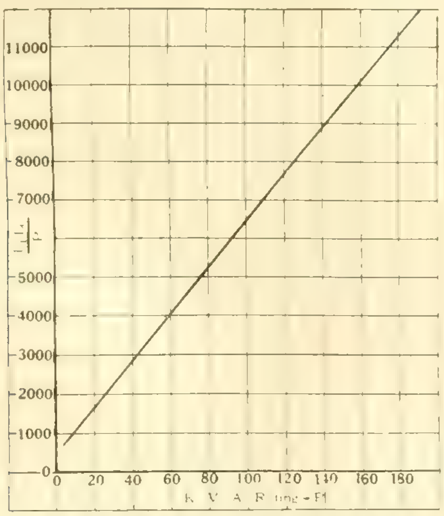


FIG. 1—THE EQUIVALENT TOTAL LOSS

Expressed as a percentage of the transformer k.v.a. rating is directly proportional to the k.v.a. rating.

RELATION BETWEEN THE TOTAL EQUIVALENT LOSS AND THE DIMENSIONS, WEIGHT AND COST OF A TRANSFORMER

If in equation *7* the output and space factor remain constant and the size of the transformer be changed by varying its dimensions, the equivalent total loss may be expressed in terms of the dimensions, as follows: –

$$L_i L_c \propto \left(\frac{1}{b}\right)^2 \ldots\ldots\ldots\ldots (10)$$

This follows from the fact that the areas of the magnetic circuit and the winding sections are proportional to the square of b, and the weights of iron and copper to the cube of b, and y is equal to 2.

Example:—If the dimensions of a transformer be increased 10 percent, what will be the change in the equivalent total loss?

From equation 10 the equivalent total loss becomes $\left(\frac{1}{1.1}\right)^2$ or 0.83 times the original value.

Further, since the weight and cost of the active material varies as b^3 this expression may be written,—

$$L_i L_c \propto \left(\frac{1}{Weight}\right)^{\frac{2}{3}} \ldots\ldots\ldots\ldots (11)$$

and

$$L_i L_c \propto \left(\frac{1}{Cost}\right)^{\frac{2}{3}} \ldots\ldots\ldots\ldots (12)$$

Example:—If the weight and cost of the active material in a transformer be increased 10 percent, what will be the change in the equivalent total loss?

From equations 11 and 12, the equivalent total loss becomes $\left(\frac{1}{1.1}\right)^{\frac{2}{3}}$ or 0.93 times the original value.

If the copper loss is constant,—

$$Cost \propto \left(\frac{1}{L_i}\right)^{\frac{3}{2}} \ldots\ldots\ldots\ldots (13)$$

and when the iron loss is constant—

$$Cost \propto \left(\frac{1}{L_c}\right) \ldots\ldots\ldots\ldots (14)$$

Example:—If the iron loss of a transformer be reduced 10 percent, how much can the cost of its active material be reduced, the copper loss remaining constant?

From equation *13* the cost of the active material becomes $\left(\frac{1}{0.9}\right)$ or 1.18 times the original value.

RELATION BETWEEN THE COST OF THE ACTIVE MATERIAL FOR A GIVEN IRON LOSS AND THE QUALITY OF IRON IN THE MAGNETIC CIRCUIT

For a constant iron loss, if the quality of the iron in the magnetic circuit be improved, less material may be used. Equation *13* gives the relation between the iron loss and the cost of the active material but, if the percent quality of the iron be improved, the result is equivalent to increasing the iron loss of the transformer the same percentage, therefore,—

$$Cost \propto (percent\ iron) \ldots\ldots\ldots\ldots (15)$$

This assumes that the magnetic density in the iron is not limited by its saturation, but that it may be freely varied through the range permitted by the change in the quality of the iron.

Example:—What would be the relative costs of two transformers, one built with 100 percent quality of iron and one built with 90 percent quality of iron?

From equation *15* the cost of the transformer with 90 percent iron is (0.90) or 0.85 of the cost of the transformer with 100 percent iron.

VARIATION OF THE COST WITH THE SPACE FACTOR OF THE WINDING SECTION

With everything constant except the dimensions of the transformer and the space factor of the winding section, it will be found from equation *7* remembering that the cost of the active material varies as b^3, that,—

$$Cost \propto \left(\frac{1}{S_f}\right) \ldots\ldots\ldots\ldots (16)$$

Example:—What will be the relative cost of the active material in two transformers, one of which has a ten percent better winding space factor than the other?

From equation *16*, the cost of the transformer with the better space factor is $\left(\frac{1}{1.10}\right)$ or 0.75 of the cost of the transformer having the poorer space factor.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

JUNE 1918

Drying and Baking Ovens

Dipping and baking armatures and fields—

1—Keeps out moisture and dirt.
2—Acts as bond to prevent vibration.
3—Improves insulation.
4—Decreases maintenance.
5—Increases heat conductivity.

Where the service does not require a large oven, a small oven of comparatively cheap construction may be built and operated with good results.

OVEN CONSTRUCTION

A good oven may be constructed of two inch asbestos block supported outside and inside by one-sixteenth inch sheet steel. An oven six feet high, 3.5 feet wide and 4.5 feet deep makes a very convenient size for average operating conditions. The door should be air tight and for this reason may best be placed on the 3.5 foot side, if the whole side is to be taken up by the door.

FIG. 1—STEAM BAKING OVEN

Showing arrangement of steam pipes, ventilating equipment and temperature indicator.

HEATING UNITS

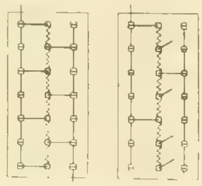
The heating units may consist of steam coils or electric heaters. Steam coils should be arranged on the floor. Twenty-five standard 1.5 inch pipes the length of the oven will be sufficient in most cases, for low-pressure steam. The joints should be welded to avoid the possibility of escaping steam giving the apparatus a vapor bath.

If electric heaters are used it will require six 3 kw heating units to heat the oven and load up to a temperature of a 100 degree C. in approximately two hours. A smaller number of heaters will require a correspondingly longer time. After the baking temperature is reached, heat will be required only to supply the radiation losses and heat the ventilating air. One three kw unit will be sufficient for this, or still better, four units of this size may be used, connected in series-parallel, as shown in Fig. 3. Seven single-pole double-throw switches will be required for this change. The exact amount of heat required to maintain a given temperature cannot be predetermined accurately, as the construction of the oven, ventilation, temperature of the surrounding air, radiation and number and size of armatures or fields being dried or baked will affect the heat consumption. The amount of heat required may readily be determined by test.*

VENTILATION

The oven must always be ventilated so that the gases may escape. If it is not ventilated the air will become saturated and incapable of absorbing any more moisture. For the above size of oven an air inlet consisting of six two inch holes equally spaced, three in the front and three in the rear, at the bottom of the oven are recommended. The air outlet may consist of a hole six inches in diameter in the center of the top. Ventilation may be varied by means of a damper placed in this opening. Complete change of air should take place at least three times an hour. While these openings will probably be found of sufficient size, the correct openings for a given installation may best be determined in practice.

If a more elaborate oven is desired, the heating coils may be placed in a chamber below the floor, the air being admitted to the bottom of this chamber passing over the coils and up through a perforated floor to the oven. An exhaust fan at the air outlet is also advisable.



FIGS. 2 and 3—CONNECTIONS OF SEVEN DOUBLE THROW SWITCHES FOR SERIES PARALLEL COMBINATIONS

Fig. 2—Switches closed to give full parallel connection to bring oven up to the operating temperature.

Fig. 3—Switches closed to give series parallel connection of four heating units.

TEMPERATURE

Temperatures may be read by means of a thermometer inserted through a small hole in the oven. As the temperature in the oven may vary at different places, readings should be corrected so that the oven is kept at the average desired temperature rather than the indicated temperature as measured in one place by the thermometer. If the cost is not prohibitive, a recording thermometer is more desirable than the bulb thermometer mentioned above. This also should be calibrated to read the average oven temperature.

OVEN TRUCK

A truck similar to the one shown in Fig. 1, is very good for baking armatures in a vertical position. It is of steel construction with a number of holes 6.5 inch in diameter cut in the truck floor, so that the commutator end of the shaft may pass through the holes, allowing the commutator to rest on the floor and support the armature. The truck floor is 13 inches above the oven floor allowing ample clearance for the commutator end of the shaft. The hole in the floor of the truck should be somewhat larger than the shaft, so that there will be ample room for the passage of warm air up through the ducts of ventilated type motors.

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*Instructions for dipping and baking are given in the JOURNAL for April, '18, p. 137.

THE ELECTRIC JOURNAL

INDUSTRIAL APPLICATIONS OF ELECTRIC HEATERS

JUNE 1918

The Manufacture of Mica Cells

In the manufacture of mica cells, troughs, etc., the material out of which they are made must be heated before it can be formed into the desired shape. Flat pieces of built-up mica of the proper size and shape to make the finished cells or troughs are placed on a warming table and heated until the shellac bond softens, when they are removed from the table and while still warm and the shellac is still soft, are formed to the desired shape and held thus until they have cooled and the shellac hardened. Long cells require a longer time to form and in order to prevent portions of the mica from cooling, they are formed over a steel bar which has previously been heated on the warming table.

FIG. 1—WARMING TABLES

The warming tables on which this is done are 34 in. long, 18 in. wide and 4 in. high, being designed to be placed on an ordinary work bench. Each table consists of two heavy steel plates between which the heaters, four in number, are clamped.

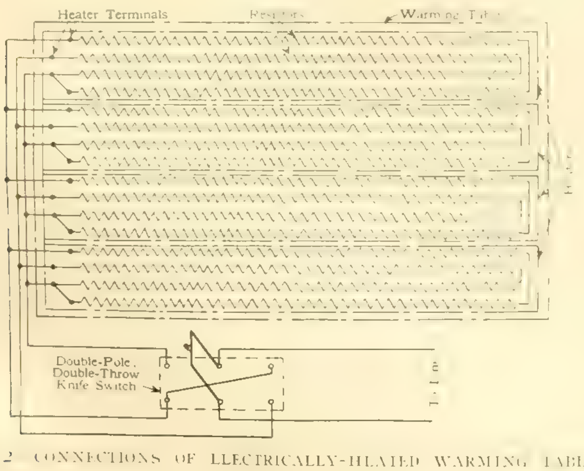

FIG. 2—CONNECTIONS OF ELECTRICALLY-HEATED WARMING TABLES

These plates are mounted in an iron box and are provided with legs at the four corners. There is a space between the plates and the bottom of the box, which is filled with a heat insulating material.

The heaters themselves consist of two flat ribbon resistors assembled in mica sheaths, and enclosed in a strong steel casing, the ends of the resistors being brought out to terminals mounted on the casing. Each heater when completely assembled, ready for installation in the warming table, is 33 in. long, 2.25 in. wide and $\frac{3}{16}$ in. thick. The heater unit has a

TABLE I—COMPARATIVE HEATING CHARACTERISTICS

STEAM	GAS	ELECTRIC
Steam supply not always available, especially where most convenient to install warming table.	Not always available especially where most convenient to install warming table.	Now available practically everywhere, and tables can be installed where most convenient.
Expensive and not always convenient to install piping.	Expensive and not always convenient to install piping.	Circuits can be easily and cheaply extended.
Considerable loss of heat from piping especially where long piping is necessary.	Considerable loss of heat to the surrounding air	No loss of heat from wiring, and practically none into the surrounding air.
Temperature is limited by steam pressure. If but even moderately high temperatures are required, it involves the expense of a licensed steam engineer who might otherwise not be required.		Temperatures obtainable are far in excess of those that can be obtained from steam.
There is a probability of leaks from steam piping, especially at high pressures	There is danger of leaking gas forming an explosive mixture causing explosions and fire.	No leakage encountered with the use of electricity.
As temperature varies with the pressure it is necessary to vary the steam pressure where different temperatures are required, which is inconvenient, and difficult of duplication.	Necessary to regulate flow of gas to obtain different temperatures, which is inconvenient, and difficult of duplication.	Easy to obtain different temperatures by proper use of switches, and exact duplication is easy and convenient.
	The products of combustion are unpleasant and unhealthy, and make bad working conditions, especially in Summer.	There are no unpleasant or unhealthy products of combustion, and working conditions are better than with any other fuel.
Insurance rates are high on account of the use of a high pressure steam boiler.	Insurance rates are high because of danger of fire and explosions.	Insurance rates are low on account of absence of any possibility of fire and explosion.
	The pressure is liable to vary and when a gas pressure regulator is used, there is a possibility that it will get out of order and cause table to cool off or overheat and perhaps spoil the material that was being heated.	There is no danger of table overheating, or cooling and spoiling the material.
Moisture is liable to be absorbed by the material, which would be harmful.	Soot given off in the combustion of gas may soil and otherwise damage the material being heated.	No possibility of the material becoming wet or dirty, or otherwise damaged from products of combustion. May be made portable.
		Production greater than with gas or steam since tables can be placed where most convenient, or moved around to suit conditions.

maximum rating of 1000 watts, but connections are made between the terminals and a D-P, D-T knife switch having a special cross-connection, whereby the input to each heater section is either 250 watts or 500 watts, according to the side

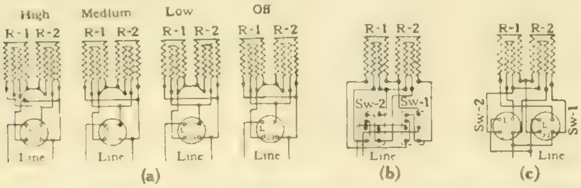

FIG. 3—CONNECTIONS FOR CHANGING HEATERS FROM SERIES TO PARALLEL

(a)—Using snap switch for three heats; (b)—Using two knife switches for eight heats and (c)—Using two knife switches for thirteen heats.

on which the switch is closed. The total input of the table thus may be either 1000 watts or 2000 watts.

With the maximum input of 2000 watts, the table can be brought up to operating temperature in three hours. This input is sufficient to maintain the surface of the warming table at 160 degrees C. continuously, which is the proper operating temperature. If it were necessary to bring them up to operating temperature more quickly, by the use of an additional switch or the substitution of a three-heat switch, as shown in Fig. 3, both heaters could be connected in parallel, giving an input of 4000 watts, and reducing the time. The length of time required to heat the mica pieces varies with the thickness and amount of shellac present in the mica from one-half to one minute.

That these tables have proved satisfactory is shown by the fact that they have been in constant use for more than eight years, without any attention whatever having been given them in the way of repairs. The reason for their success as compared with similar tables heated by steam or gas are as shown in Table I.

When all the advantages of such electrically-heated warming tables are realized, there should be a great demand for these devices. Their use is not limited to the warming of mica, as there are a wide variety of uses to which such tables can be put.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1596—ROTARY CONVERTER BRUSH WEAR—We have a 150 kw., four-pole, three-phase, 25 cycle rotary converter, which is compelled to build up always in the same direction. All the brushes on the positive studs are wearing rapidly whereas the brushes on the negative show no signs of wear. The polarity was ascertained by means of a voltmeter and checked. All studs have the same number of brushes and the same grade. The direct-current system is two wire, 220 volt.

L.T.F. (LA.)

On a machine carrying direct current, there is an action resembling electrolysis between the brushes and commutator, which tends to eat or wear away the brushes of the negative arms (i.e., the arms on which the current returns to the machine) and deposit copper on the brushes of the positive arms, (i.e., the arms on which the current leaves the machine). In other words, the current simply carries the carbon of the brushes and the copper of the commutator along in the direction it is flowing. On machines having good commutation and smooth commutators, this action is usually very slight. Poor commutation causes the brushes to burn and aggravates the apparent electrolytic action. This burning roughens the commutator, which in turn increases the burning, and so on, making the action cumulative. The rough commutator mechanically wears both the positive and negative brushes but, on account of this apparent electrolytic action, the negative brushes receive an additional electrical wear which causes them to wear away more rapidly than the positive brushes. These are general statements and in each particular case the relative effects of the various factors concerned depend upon local conditions. In this particular case, the excessive brush wear is apparently on the positive brushes, which is adverse to the above explanation, and which seems to indicate that the reference in the question to the positive and negative brush arms has just the opposite meaning from the above definition of the positive and negative arms. It is suggested that you check the polarity of the brush arms in line with the above definition, and see if the excessive wearing of the brushes on one set of arms cannot be accounted for by the explanation given.

M.W.S.

1597—DELTA CONNECTION OF TRANSFORMERS WITH UNEQUAL VOLTAGE RATIO—Can the following transformers be used on a three-phase circuit, delta connected on both primary and secondary? What would be the effect of the extra voltage on the secondary side of No. 2 on their operations where connected as above? Two of these transformers 1 and 2 are already operating on open delta primary and secondary motor loads. 1—200 k.v.a., 6600—220/440 volt. 2—200 k.v.a., 5940/6600—240/480 volt. 3—200 k.v.a., 6600/440 volt.

M.C.A. (MO.)

When three transformers, one of which has a voltage ratio different from the other two, are connected in delta, the effect is the same as though the delta connection were opened and a single-phase voltage introduced. This voltage acts to circulate a single-phase current around the delta and is resisted by the impedance of the three transformers in series. In the present case, the circulating current will be something like 1.5 times full-load current. It will obviously be impossibe to carry any external load on the bank under these circumstances.

J.B.G.

1598—COMMUTATOR TROUBLE—We have in service a 1000 kw., 600 volt. 720 r.p.m., compound-wound, motor-driven generator with both interpoles and pole face or compensating winding. It has eight poles, eight brush studs, twelve brushes per stud. This generator has been in daily service for the past two years supplying current to a railway load of approximately 75 percent full load current during the off peak load, 125 to 150 percent load during the peak load hours extending over a period of 2 to 2.5 hours. Until ten days ago, the commutation has been absolutely sparkless for all loads and all changes in load up to and including the 150 percent load. During the past ten days sparking has developed and I note from two to four commutator bars blackened at eight equally distant points around the commutator. Sparking occurs as these bars pass under the brushes. The side mica on commutator is milled out to a depth of approximately 1/16 inch. I have inspected the commutator for leaf mica; likewise ground it to eliminate flat spots, however, the eight black spots re-appear after several hours operation at normal load. The brushes are on mechanical neutral, all equally spaced around the commutator and in line with the center line of armature shaft. The commutating field and all electrical connections and adjustments same as made by factory. The armature is free from grounds, with no local heating of any of the armature conductors. The armature is equalized on every slot conductor. Shortly before this sparking developed the machine arced over due to heavy short-circuit on the generator leads. Do you attribute this sparking and blackening of bars to poor electrical contact between commutator and armature coils or armature coils and equalizer connections? There is no visible indication of poor contact.

C.E.O. (PA.)

Commutator bars blackened at equally spaced points on the commutator periphery are generally caused by an open circuit in the armature winding. This may be at the point of connection to the commutator necks or, most likely, at the rear of the winding, if two-piece armature coils are used, and the joints taped over. A defective joint may have

good electrical contact at stand-still, and still have a very high resistance when the machine is running at full speed. It is unlikely that a few loose cross-connections would cause this trouble, provided the armature is reasonably well-centered. It is recommended that all joints in the armature circuit be soldered. F.T.H.

1599—LIGHTNING ARRESTER ELECTROLYTE—Is the old electrolyte from aluminum electrolytic lightning arresters good for fertilizer or any thing else? C.A.D. (MINN.)

The value of old electrolyte from electrolytic lightning arresters as a fertilizer would be so small as to be negligible. We do not recommend it. G.C.D.

1600—TEST VOLTAGE ON REWOUND ARMATURE—I have been instructed to see that all direct-current armatures wound in my department are tested for ground with 2300 volts. I have understood that 550 volts test to ground on 250 volt and 1100 volts on 500 volt armatures, was sufficient ground test for all ordinary purposes. A short time ago three coils broke down during a test of 2300 volts to ground on a 250 volt armature. A step up transformer of two kilowatts capacity was used. A one kilowatt transformer of 2300 volts to ground was used first, showing no ground, but the two kilowatt broke down the three coils. This armature was well insulated and impregnated with varnish, but was still sticky, not having had time to dry thoroughly. Please advise the proper voltage for ground tests of the above mentioned armatures. R.P.M. (UTAH.)

The rules of the American Institute of Electrical Engineers require that all motors or generators stand an insulation test of twice the line voltage plus 1000 volts for one minute. This would require a test of 2300 volts for one minute on a 650 volt motor, or generator. Usually the same insulation is used for 250 volts as for 650 volts. Therefore, armatures for 250 volts of 5 to 50 horsepower should be expected to stand 2300 volts if they have the same insulation as for 650 volts. More careful winding is required to meet these higher tests than the lower ones and it will be more expensive, especially if the winder is not a skilled man. From the service standpoint, the armature has better assurance of having a long life since there will not be places much weaker than the average. If a testing transformer's capacity is too small for the armature being tested, the test voltage is pulled down and may not puncture the insulation. The one kilowatt transformer is probably too small for the larger motors which you mention. It is generally advisable to test armatures before banding or putting wedges in place with a higher voltage than will be used on the completed armature, as defects can more easily be repaired at that time. If an armature is only partly rewound, a test of 2300 volts is too high; 550 volts for a 250 volt armature or 1100 volts for a 550 volt armature would provide a fair test for such rewound armatures. J.L.R.

1601—BREAK DOWN OF CURRENT TRANSFORMER—What is the real cause of a breakdown of a current transformer when the secondaries are left open—high induced voltage or excessive core losses (eddy and hysteresis)? J.I.D. (CAL.)

A current transformer operating with secondary circuit open has a high voltage developed in the windings as the entire primary current is magnetizing. Also the iron, being saturated, has high losses and may get very hot. Such a transformer is apt to fail due to high voltage between turns. Even if the insulation withstands this voltage it is apt to fail from the excessive temperature of the core. For a discussion of these conditions see article on "Characteristics of Current Transformers on Open Circuit", in the JOURNAL for February 1918, p. 48. W.R.W.

1602—FIELD DISCHARGE RESISTANCES—Is it necessary to have field discharge resistances across the fields of 150 to 225 kw, 600 r.p.m., 60 cycle alternators with a direct-current potential of 30 to 135 volts? It is necessary to break the fields under full-load conditions. J.H.B. (WYO.)

Field discharge resistance should be used on fields of alternators having the above characteristics and operating under normal conditions. Operating conditions which require the opening of the field circuit under full-load conditions, as mentioned above, on machines of this size are very rare. However, if such is the case, a field discharge resistance will be even more necessary, on account of the greater amount of energy which must be discharged by the field. M.W.S.

1603—GENERATOR WINDINGS—A direct-current, 550 volt, six-pole, direct connected compound-wound generator has a commutator of 152 segments, the throw of the armature coils being 1 to 51. What effect will it have on the voltage if these coils are connected with a throw of from 1 to 52, the generator operating at the same speed? C.A.K. (KY.)

An armature having 152 commutator bars and a throw of bar 1 to bar 51, would have two independent or "sandwich" series windings, making a total of four parallel circuits. That is, starting with any bar as number 1, and following the winding, it would be found to close upon itself after every odd bar had been included; and, beginning with one of the remaining bars, the other winding would be found to close upon itself after all the even bars had been touched. The bars would be met in the order 1, 51, 101, 151, 49, 99, 149, 47, 97, and so on, every other bar being taken in before the winding re-entered itself at bar 1. As such a winding on a six-pole machine cannot be properly cross-connected, there is nothing to hold the two windings at the right relative potential at every instant, and a generator so wound would not be certain to operate satisfactorily. If the winding were connected with a throw of 1 to 52 instead of 1 to 51, it would be an ordinary series or two-circuit winding. The order of connection to the bars would be 1, 52, 103, 2, 53, 104, 3, 54, and so on, every bar being taken in before the winding closed upon itself at bar 1. With this arrangement there would be half as many parallel circuits as before, and twice as many conductors in series, so the voltage generated would be double that of the four-circuit winding. F.L.M.

1604—POLARITY INDICATOR—Can you tell me what the liquid is in a small liquid polarity indicator of the kind in which, when it is applied to a circuit, the liquid at the negative electrode turns red? E.M. (MO.)

A liquid polarity indicator of the kind mentioned in the question can be made by using a neutral solution of sodium sulphate, to which has been added a few drops of phenolphthalein. This solution is clear when neutral or acid and turns red when basic. The formation of sodium hydroxide at the negative pole will cause the solution to turn red and indicate the polarity. L.W.C.

1605—CHANGING INDUCTION MOTOR DESIGN—We have a number of 220 volt induction motors which we would like to change to 550 volts. As I cannot do this by reconnecting, I would like information in regard to changing the design *i.e.*, a formula or method which I could apply to any induction motor. E.B.Y. (MASS.)

The first consideration in changing these motors from 220 to 550 volts is to note that the number of effective conductors per slot must be increased in the ratio of 550 to 220, or in other words, there must be as close as possible to 2.5 times as many effective conductors in the slot. This of course requires a corresponding reduction in the size of the individual conductors, the aim being, however, to get the same total copper section in the slot if possible. This at times is not possible as the space factor is poorer with the greater number of small wires, since there is a greater proportion of insulation. By effective conductors is meant that parallel connections of the groups and paralleling of the wires in the coils must be accounted for in determining what the voltage per conductor is, as this must be kept practically the same in going to a higher voltage, the increase in number of conductors taking care of this. See also the article on "Reconnecting Induction Motors" by A. M. Dudley, in the JOURNAL for Feb. 1916. B.B.R.

1606—SINGLE-PHASE LOAD ON POLYPHASE METER—Assuming that a printing office has three-phase, 220 volt service and that they desire to use a single-phase melting pot or motor, and assuming that there are times when the three-phase service is not supplying current to any other piece of apparatus than the single-phase heating elements or motor, would a polyphase meter register accurately under these conditions? Also, would it be possible to get accurate registration by using two single-phase meters instead of the polyphase meter under these conditions? C.E.F. (MINN.)

Any good polyphase wattmeter, properly connected, should, within the limits of ordinary commercial accuracy, measure correctly any polyphase load which passes through it. A single-phase load can be considered as an exceedingly unbalanced polyphase load and the meter should measure the single-phase load on any phase as accurately as it does any unbalanced or balanced polyphase load. The same statement applies to the metering of polyphase loads with two single-phase wattmeters, except when the resultant power-factor is below 50 percent. Certain combinations

of unbalanced polyphase load produce a very low power-factor in one or more phases. Thus with certain combinations of lamp loads, and more especially with inductive loads, it is possible for one of the single-phase meters to run backwards. If the meter registered as accurately when running backwards as when running forwards, the power would still be correctly measured if the algebraic sum of the readings was taken at all times. This is practically true at full loads, but at light loads, on account of the light load adjustment which is used to overcome the friction of the meter, the meter will be slow when run backwards by twice the light load adjustment. However, this is of small importance as, although the percentage error on this particular meter is high at light loads, the gross error would be only a small percentage of the total load measured. Polyphase watthour meters and two single-phase watthour meters are regularly used for the metering of polyphase loads which have single-phase lights as part of the load.

C.R.R.

1607—Banding Generators—In the April 1917 Journal in "Railway Operating Data", you state that steel wire is the proper material to band direct-current motor armatures. We banded the armature of a 700 ampere, 600 volt direct-current generator with steel wire and when we got the load on it the wire expanded and started to come off. We had to use brass wire. On a 30 kw direct-current generator the wire got hot but did not come off. Why is steel wire all right on direct-current motors and not on direct-current generators?

R.MCK. (N.H.)

There is no essential difference, so far as the banding is concerned, between a direct-current motor and a generator. It is probable that the heating in the steel bands in the two generators mentioned was caused by the way in which the bands were applied. They would have become equally hot if the machines were operated as motors. Steel wire is regularly used for banding direct-current generators and motors even of the largest size. Steel wire bands are subject to heating from one source which is absent when brass is used, *viz.*, magnetic hysteresis. Cases of hot bands have been investigated, but in most cases the trouble has been found to be due not to heat generated in the bands themselves but to conduction of heat from adjacent hot parts. The need of using wire of high tensile strength, and of banding under considerable tension, if loose bands are to be avoided, is obvious. A matter of fundamental importance is to band in such a way that the completed band rests solidly on the armature teeth. If the coil projects from the slot sufficiently to prevent this firm contact, the shrinking of the coils when in service will result in looseness of the band. This last point is especially important and may have been the cause of the trouble, for it is obvious that, as the tension of the bands is taken by insulation on the coils, the band tension will be released as the coil insulation shrinks with service.

F.L.M.

1608—Taps on Transformers—The writer has a 10 kw, 440 to 110-220 volt transformer which has 480 volts on the primary coils, which brings up the secondary voltage to about 125 volts. I would like to know if I could not open the secondary winding and take out taps on both series coils of the secondary coils to bring the secondary voltage down to about 110 volts, as I cannot reduce the primary voltage on account of other transformers with 480 volt primaries. Please explain how to take the transformer apart and take out taps.

E.M.D. (WASH.)

To put taps on the two low-voltage coils, it would be necessary to disassemble the entire transformer. That would be difficult for any one not equipped to do that class of work. A better way to arrive at the same results is to add turns to the high-voltage coil. Assuming the transformer to be a 60 cycle, Westinghouse Style No. 119259A, this can be done by first taking transformer from case then taking lead on the right hand side (facing high voltage side of transformers) splicing a No. 10 insulated wire to it and winding 16 turns in a clockwise direction around the outside coil. The wire should be insulated with a material that will not deteriorate in oil, and stand an insulation test of 2200 volts. The wire can be threaded between the iron and coil, care being taken not to damage the insulation on wire. These turns are added to the high voltage coil which is in the middle of complete set of coils. The number of turns for any other transformer can readily be determined by trial.

C.E.

THE ELECTRIC JOURNAL

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Coal and the War

At the present time, no industry of the country is of more vital importance than the production of coal. While it may be possible to produce a considerable part of our power requirements by other means, we can spare neither the time nor material to effect such changes during the war. The demand upon our coal burning industries has jumped in three years to a volume which under normal conditions would have taken 25 years to reach. Some shortage was inevitable under these conditions. The actual shortage of bituminous coal during 1917 was about 50 million tons, in spite of a production, about 15 percent above normal, totaling 600 million tons.

There appear to be three features which require very definite attention to effect a satisfactory solution of the general problem:—

1—Increased production.

2—The provision of sufficient cars and the adequate arrangements for their transportation.

3—The conservation of fuel on the part of all users, including the mine operators.

While economy in the use of fuel is practically essential we cannot solve the problem by economy alone. We have at best never produced in one year better than 25 million tons short of all present requirements, even after all suggested savings are effected.

It is not necessary to have the report of the Fuel Administration to realize that we waste a great deal of fuel in this country every year, and lasting good will result from our experience of last winter if we consistently adopt and practice the methods of economy as suggested by the Administration, which include the following:—

1—The more general use of improved mechanical stokers.

2—The use of central station power and elimination of small isolated plants.

3—The elimination of unessential stops on city and suburban car lines.

To which may be added the possibility of saving thousands of tons annually by the more extensive use of electricity in the mining of coal, where power may be obtained from a large power system, and the elimination of the small low-efficiency plants extensively used for hoisting and other mining operations.

Now that the vital importance of saving fuel has been given wide publicity, the opportunity for extending the use of electricity is far greater than ever before, and no coal operator can remain inattentive to its advantages. This applies primarily to such localities as can secure power from large existing plants, but it is not beyond the possibilities of the next few years, if present conditions continue, to expect the extension of such plants and the building of new large stations until the entire industrial field, including the coal fields, are fully supplied from high tension lines.

It is impractical to consider the general electrification of trunk line railways, as a war measure, because the great saving in fuel which would result is more than offset by the time and material which would be involved. However, by methods which are practical, we should effect a saving of 25 million tons annually, and if we add the same tonnage as increased production, our present and indicated future shortage is wiped out.

This saving of fuel by the methods suggested will increase the demand for electrical apparatus in general, and it should be reasonable to assume that, having the coal deposits and a fundamental need for fuel in our industrial and power plants, in this day of government regulation and control, ways and means will be found to increase our production by the necessary 25 million tons and also for transporting the total production to the plants where it is demanded and efficiently used.

With present-day improved methods of mining, new operations to produce this increase will involve an investment in electrical apparatus for use at the mines of the value of between three and four millions of dollars. When we consider this, in addition to approximately an equal amount which is spent annually incident to the apparatus now in use, it is evident that we should anticipate a strong demand for electrical apparatus in the bituminous fields, especially such apparatus as is used in substations or for the conversion of power and in its application within and near the mines.

H. H. SEABROOK

Arc Welding of Steel

The successful repairing of the interned German ships in our ports has called the attention of the public to an art which was rapidly developing in this country but of which little was generally known, before we entered the war. Arc welding has been used for minor repairs for a number of years but was looked upon with some suspicion when proposed for important applications where failure would entail serious results.

The railroads of the country had been extending the use of the arc welding process, however, and were making repairs of such important members as locomotive frames, cylinders and boilers with entire success. In fact the results have been so satisfactory that the report from one railroad shows a saving of $200 000

per year in repair work from an initial investment of $40 000 in welding equipment. The welding supervisor in this case states that this saving could be increased five times with an adequate amount of welding equipment and operators to use it.

With such skill and equipment available, when the damaged German ships were to be reconstructed the men trained in similar repair work stepped forward and accomplished the repair of the broken parts in a surprisingly short time. The results have been entirely satisfactory. The writer has seen some of this work being done and finds no question of its reliability in any quarter.

Arc welding then came to the attention of our military and naval authorities from another source. It was found that the British admiralty had been using this method extensively both in repairs and new construction since the beginning of the war. The new construction consisted largely of the fabrication of the vast numbers of mines, depth bombs, and similar munition supplies and in addition some pioneer work in the construction of steel barges. For that reason Captain James Caldwell came to the United States at the request of the Emergency Fleet Corporation to assist in the interchange of information on the art between this country and Great Britain. The present electric welding committee of the Emergency Fleet Corporation is an outgrowth of this effort.

From its very nature, arc welding is a stranger and subject to suspicion until a friendly acquaintance is consummated. A riveting job, on the other hand, is a straight-forward operation and within its limitations can obviously be repeated with certainity. The one thing that militates against arc welding is the difficulty of determining definitely whether a completed job is good or bad without destroying it. As a matter of fact, so far as known at the present time, security can only come from familiarity with the process and a careful control of the work while it is being done rather than by any inspection method applied to the completed job. Further research work is being carried on by the electric welding committee in the endeavor to determine more exactly the best methods of doing the work and to define in a general way the characteristics of the equipment and material required.

Obviously the immediate application of arc welding on new ship construction is in its substitution for riveting in securing the thousands of fittings on a ship. It is the placing of these fittings that frequently consumes so much time after a ship is launched before it is ready to put to sea. Every effort should be made to bring to the attention of shipbuilders and demonstrate the economy and speed of arc welding for this kind of work.

Beyond this, moreover, provisional plans are on foot to try out electric welding, including both heavy spot welding and arc welding, for the more responsible portions of ship construction. It is fair to predict that the time is not distant when certain types of steel ship construction will be entirely accomplished by electric welding methods with a great gain in speed of construction and a material saving of weight and material.

R. P. Jackson

Educational Advertising

In the days of Horace Greeley and George D. Prentice, newspapers moulded opinion, now they merely reflect it. Hence, if the traction companies wish that favorable publicity be reflected, they must furnish the papers with something to reflect. The results which are obtainable in this way are discussed in this issue by Mr. W. H. Boyce.

Members of the A. E. R. A. hold conventions and conferences. Each knows his own troubles and has sweat over their solutions. They interchange views, read able papers, give inspiring addresses, gather at "round tables," mutually interest, entertain and instruct. Then they go, each to his home, and await the published records of these doings. How many of them find, and take the straightest path to the broad and definite solution of their difficult problems. Executive, financial, engineering and managerial knowledge they have, and probably to spare, but have they salesmanship knowledge? They seem to have gone after human nature backwards like a crawfish, Only recently, and then by only a few, has real salesmanship been applied to the solution of their many and arduous problems. Salesmanship is merely the sale of convictions; it is displacing the other fellow's opposing ideas with your own, and in a tactful and sincere way. It is eminently more difficult for the other fellow to perceive your problems, unaided, than it is for you to solve them. He has problems of his own absorbing his time and thought. He is not begging to be shown. He is willing to be shown, but you who are entrusted with your companies' welfare must take the initiative. You have too long felt that you had the handle-side of the jug; when you have made an effort, you have tackled the wrong fellow—the politician or the Public Service Comission. Go after their masters—the people. When you are self-assured of the soundness of your purpose toward the people, then just tell them so—and do it like salesmen. If we can't trust the people we had better sell out and leave them to find their own means of transportation.

Forceful, winning publicity is the largest approach to a panacea for the unsatisfactory relations between public utility companies and the people. What is needed is a plan of action and then a vigorous and continuous execution of it.

T. H. Bailey Whipple

Arc Welding of Mild Steel

O. H. Eschholz
Research Engineering Department
Westinghouse Electric & Mfg. Company

IN VIEW of the successful arc welding repairs which were made recently in the interned German ships in United States ports, the extensive application of this process to the repair and construction of all types of vessels by the British admiralty and the recent authorization of the Emergency Fleet Corporation for the construction of ten completely arc-welded vessels, the subject of arc welding becomes of unusual interest. The most important phase of a welding operation is the proper control of the process. The following article presents what is probably the first concise treatment dealing exhaustively with those operating factors which determine the production of consistent and reliable welds. (Ed.)

With the adoption of electric arc welding as an essential manufacturing operation, it has become generally recognized that a clearer conception of the arc phenomena is advisable if satisfactory welds are to be consistently secured under widely varying operating conditions. The problems presented by the welding processes are particularly susceptible of solution by the chemist and metallurgist. However, investigation has shown that the adherence to a few obvious and fundamental requirements will result not only in good welding but will also facilitate the development of successful operators. Of the various arc welding ing processes, the Slavianoff, or metal electrode process, has the widest use. This method is unique in that a metal rod functions both as the electrode and weld filler. On drawing the arc the filler rod automatically attains the fusion temperature and is deposited in a molten state on the hottest section of the weld surface. As this characteristic inherently facilitates good fusion, this process is generally considered the most reliable.

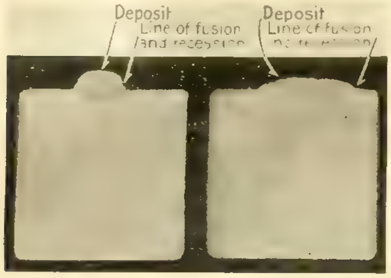


FIG. 1 FIG. 2

FIG. 1—CONCENTRATED DEPOSIT ON MILD STEEL OBTAINED BY USING A SHORT ARC LENGTH

FIG. 2—DIFFUSED DEPOSIT ON MILD STEEL OBTAINED BY USING A LONG ARC LENGTH

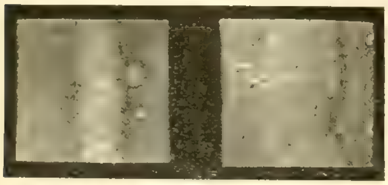


FIG. 3—CORRESPONDING TOP VIEWS OF DEPOSITS

Note the smoothness and regularity on the left in contrast to the porosity, diffusion and oxide globules of the deposit on the right.

ARC CHARACTERISTICS

On separating the metal electrodes, an arc is formed having a highly luminous central core of iron vapor, surrounded by a flame of oxides. At the temperatures prevailing in the arc stream and at the electrode terminals, chemical combinations occur instantaneously between the vaporized metals and the atmospheric gases. These reactions continue until a flame of incandescent gaseous compounds is formed which completely envelops the arc core. However drafts created by the high temperature of the vapors and that due to local air currents tend to remove this protecting screen as rapidly as it is formed, making it necessary for the welder to manipulate the electrode in such a manner that maximum protection by envelopment of arc flame for both arc stream and electrode deposit is continually secured. Fortunately, this may be obtained automatically by the maintenance of a short arc and the proper inclination of electrode to compensate for draft currents. Sections through deposits formed with a short, (22 volt) and a long, (38 volt) arc are illustrated in Figs. 1 and 2. Fig. 3 shows the corresponding surface views.

TABLE I—CHEMICAL ANALYSIS OF ELECTRODES AND METAL DEPOSITED IN WELD

Weld Fig.	Electrode	C	Mn	P	S	Si
6	Roebling	0.16	0.56	0.032	0.024	0.016
	Roebling Deposit ...	0.05	0.18	0.031	0.036	0.011
10	Coated	0.07	0.003	0.051	0.044	0.011
	Coated Deposit	0.03	0.021	0.042	0.046	0.058
11	Norway	0.049	0.021	0.025	0.007	0.08
	Norway Deposit	0.05	0.018	0.020	0.015	0.011
12	Hot Rolled Steel ...	0.13	0.50	0.012	0.045	0.011
	Hot Rolled Steel Deposit	0.14	0.14	0.012	0.039	0.011
	Cold Rolled Steel ...	0.11	0.72	0.097	0.123	0.011
	Cold Rolled Steel Deposit	0.05	0.11	0.086	0.072	0.011

A marked improvement may be noted in fusion, concentration and economy of electrode deposit, freedom from porosity and reduction in area of thermal disturbance by the use of the short arc. With the long arc, the arc flame cannot be controlled, so that it becomes impossible adequately to protect the deposited metal from oxidation. The excessive porosity, shown in Fig. 3 (right), and that usually obtained on breaking an arc are due to this cause. A short arc can be maintained on either a low or high potential system. With the former type of equipment, a greater degree of skill is required while with the latter better continuity of arc circuit is secured.

The extent of the porosity obtained on breaking the

arc varies with the arc current, the arc length, and the manipulation and type of electrode. By short-circuiting the arc automatically at a predetermined arc length, or by reducing the arc current either by decreasing the supply voltage or inserting series resistance, a slight reduction in the degree of porosity may be secured. The results obtained, however, do not appear to justify the increased investment and complexity, particularly in view of the fact that a rotary or spiral movement of the electrode on breaking the arc, or the use of an electrode which generates a large flame is equally effective. In Table I analyses of a few characteristic electrodes are given as well as the metal deposited after having passed through the arc. As a whole the action of the atmospheric gases is to refine the vaporized metal, decreasing particularly such constituents as carbon and manganese. The increase, shown in some deposits, of phosphorus, silicon and sulphur content is attributed to their absorption by the hot filler metal from the shank metal. The inconsistency in the degree of refinement shown by the hot rolled steel electrode is due to its characteristic of depositing in large globules, rather than in a spray of

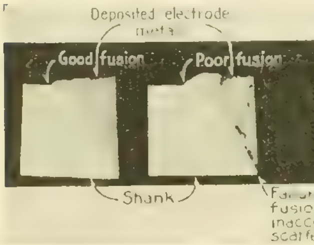


FIG. 4—CROSS-SECTIONS THROUGH FUSED PORTION

Showing shank metal and part of filler metal half-way through weld.

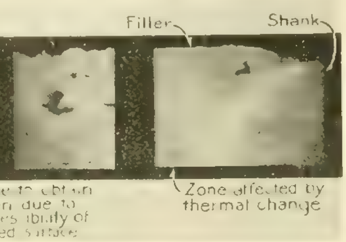


FIG. 5—CROSS-SECTIONS OF WELD MADE WITH 90 DEGREE SCARF

Showing fusion, recession from original straight scarf face and change in original structure produced by fusion temperature.

small globules, thereby exposing a smaller area to oxidation for a given volume of transferred metal. However this action tends to produce incomplete fusion.

With a wider application of the welding process a better control of the weld ingredients will be desirable. The use of refractory tubes or asbestos coating has been suggested; however, either the difficulty of electrode manipulation is increased thereby to a prohibitive degree or excessive quantities of slag are formed and unavoidably embedded in the weld. Better possibilities appear to lie in the development of an electrode which generates, during operation, an atmosphere of inert, permanent gases enveloping the arc.

FUSION

The fusion obtained at the weld surface and in the body of the filler is determined by the scarf angle, arc current and electrode diameter, as well as by arc length. Parts of weld sections correctly and incorrectly prepared are shown in Figs. 4 and 5. In Fig. 4 the abutting sections were scarfed to a total angle of 60 degrees. As a result the bottom of the weld (at the right) proved to be inaccessible to the welder, arc contact was prevented and the surface merely covered by molten metal formed above. By separating the weld shanks one-eighth inch, better fusion was obtained as shown by the weld at the left, Fig. 4, with the exercise, however, of considerable skill. The weld shown in Fig. 5

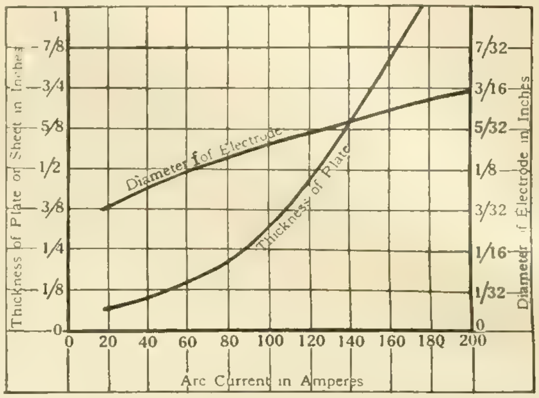
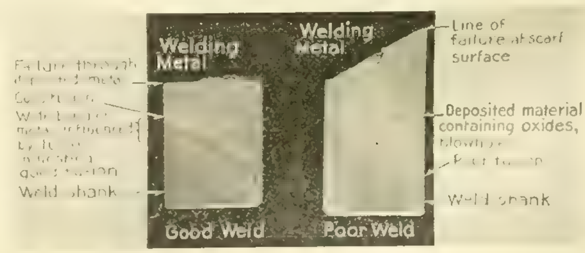


FIG. 6—RELATION OF APPROXIMATE ARC CURRENTS AND ELECTRODE DIAMETERS

For welding steel plate of various thicknesses.

was prepared by scarfing the weld surface to 90 degrees and spacing the sections one-eighth inch. This method is generally used as it materially assists in securing good surface fusion and increases the reliability of the welding operation.

Approximate values of arc currents and electrode diameters that have proven quite satisfactory for welding low carbon steel are indicated in Fig. 6. Assuming that a one-half inch steel plate is to be welded, this curve shows that approximately 125 arc amperes should be used with a five-thirty-second inch diameter electrode. It is evident from the slope of the electrode curve that a five-thirty-second inch diameter electrode is adaptable to the widest range of plate welding. The results of correct and incorrect application of this data are shown in Fig. 7. The weld at the left was made with approximately 160 amperes arc current and shows an excellent structure, the fracture occurring through the body of the weld as the ultimate tensile strength of the shank metal was in the neighborhood of 60 000 lbs. per sq. in. The weld at the right however was made



(a) (b)

FIG. 7—CHARACTER OF WELDS

Formed by using (a) arc current as specified in Fig. 6 and (b) too low an arc current.

with too low an arc current—approximately 115 amperes—with consequent incomplete fusion, porosity due to unfused, overlapping metal, and failure at the scarfed face at a stress below that demanded by machining operations.

Fig. 8 shows graphically the improvement in weld strength, and therefore fusion at the scarf and throughout the filler body, on increasing the arc current. These welds were made by two operators using Norway electrodes having an ultimate tensile strength of 47 500 lbs. per sq. in. The weld shanks consisted of one inch square steel bars having an ultimate tensile strength of 58 000 lbs. per sq. in.

SLAG AND POROSITY

The amount of slag formed and retained by the weld is dependent upon the cleanliness of the electrode and the manipulation of the arc flame to minimize oxidation. In making large welds, it is the practice to collect the slag about a nucleus by a rotary movement of the electrode and then float it to the edge of the weld. Where this method is impracticable, the slag may be removed by chipping or brushing. The porosity in arc welds is mainly due to surface oxidation, resulting from the use of a long arc. Too rapid filling and cooling produce blowholes in the congealing deposit, owing to the confinement of gases liberated from the hot weld sections and the formation of carbon monoxide on the reduction of retained oxides.

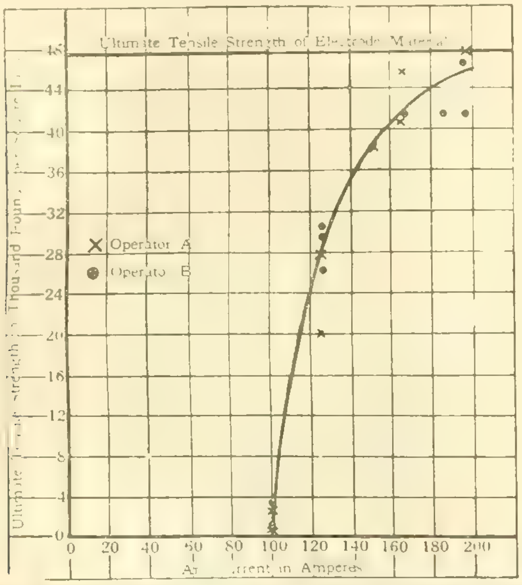


FIG. 8—RELATION OF ULTIMATE TENSILE STRENGTH AND ARC CURRENT

INSPECTION

Surface inspection of completed welds is an unsatisfactory check on the weld characteristics. Observations, or preferably an automatic record of the arc voltage and current and electrode manipulation during welding, permit the formation of a better estimate of the finished product. However, since the weld characteristics are almost entirely under the operators control it is desirable to develop his judgment by encouraging frequent examination of test welds. Most of the essential information relating to fusion, slag content and porosity may be secured by observing the surface exposed on cutting through the zone of fusion. The exposed section should be ground to a smooth surface and then dipped in a 10 percent nitric acid solution for a few seconds at a time until the line of fusion appears, as in Figs. 4 and 5. If the scarf surfaces have been completely fused and but little slag and porosity is in evidence, a large mild steel weld should have a tensile strength in the neighborhood of 40 000 pounds per square inch and a reduction of area of about seven percent.

EXAMPLES

Test exhibits are easily obtained and indicate clearly the limitations either of the process or of the welder. Figs. 9, 10 and 11 illustrate typical sections through the body of a welded mild steel plate five inches wide by one inch thick. The sections are at right angles to or parallel with the line of fusion. All of the sections indicate excellent fusion and a marked recession from the original scarfed surfaces. However, with the use of different electrodes a large variation in slag content occurs. The sharpness of the boundary line is not determined by the degree of fusion but by the reaction of the etching fluid on the filler and shank metals. The weld shown in Fig. 5 was made with a Roebling electrode; that in Fig. 9 with a coated electrode; Fig. 10 with a Norway iron electrode; and that in Fig. 11 with a hot rolled steel electrode.

STRUCTURE

During the past few years, rapid strides have been made in the improvement of steels by the proper correlation of heat treatment and chemical composition. The characteristics of high carbon and alloy steels particularly have been radically altered. It should be borne in mind, however, that with decrease in carbon content the changes produced by such treatment become less marked. Since the largest field for arc welding is in the welding of mild steel, considerable latitude is permissible in the degree of heat treatment without appreciably affecting the physical characteristics of the original

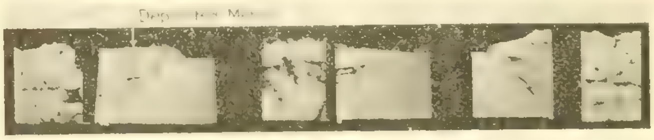


FIG. 9 FIG. 10 FIG. 11

FIG. 9—CROSS-SECTIONS OF WELD MADE WITH COATED ELECTRODE

Showing slag inclusions liable to be characteristic of deep welds when using asbestos-covered electrodes.

FIG. 10—CROSS-SECTIONS OF WELD MADE WITH NORWAY IRON ELECTRODES

Showing slag content caused by excessive oxidation characteristic of very low carbon electrodes.

FIG. 11—CROSS-SECTIONS OF WELD MADE WITH HOT ROLLED STEEL

Slag deposits are due to impurities in electrode and irregular deposition of metal caused by characteristic globule formation at electrode end.

metal. Fig. 12 indicates the structure at various stages in passing from the unaltered weld shank metal to the electrode deposit. Distinct changes of grain size and segregation of iron carbide and ferrite have been produced by the thermal disturbances incidental to the fusion and cooling of the deposit. Fig. 12 (a) shows the various structures obtained by depositing on 0.17 percent carbon steel, metal from an electrode of similar material. Fig. 12 (b) shows the original structure of slowly cooled low carbon rolled steel in zone *1* magnified

to 300 diameters. The dark areas show the location of the carbon, which occurs as iron carbide in the metallographic constituent known as pearlite. In Fig. 12 (c) the structure in zone *2* has been modified by heating to about 750 degrees and cooling below 600 degrees C. within five minutes. The temperature has been high enough to cause the iron carbide of the pearlite areas to diffuse into the surrounding metal to some exent while the rate of cooling prevented the reformation of well defined pearlite areas. This material is probably slightly harder and less ductile than that in Fig. 12 (b). The structure of zone *3* shown in Fig. 12 (d) indicates a further diffusion of the carbon content and incomplete reformation of the definite pearlite. Fig. 12 (e) shows

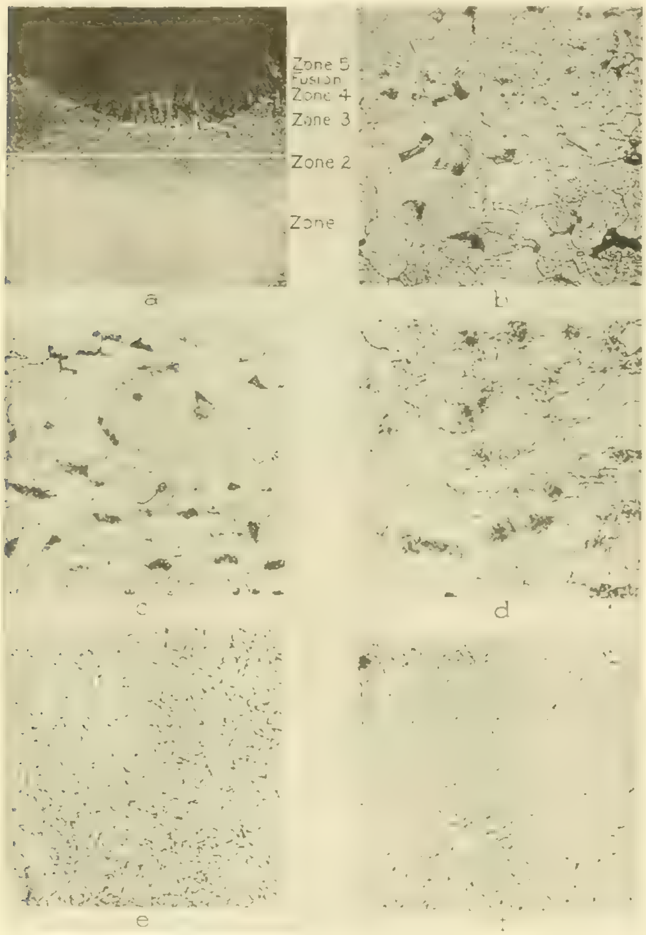
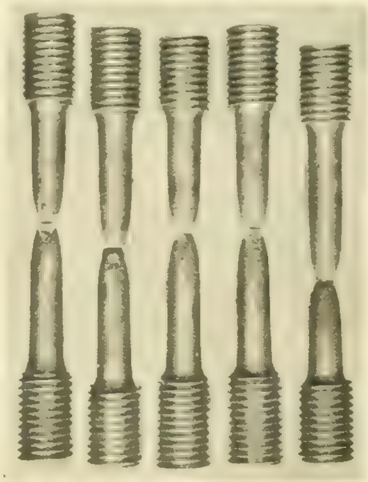


FIG. 12 SEQUENCE OF METALLOGRAPHIC STRUCTURES
On passing from original metal through fusion zone to deposited metal.

the metal in zone *1* which has been heated to a temperature of 950 degrees C. The diffusion of the pearlite areas has been complete and the rate of cooling so rapid that the pearlite areas formed are small and uniformly distributed. This metal has probably a higher tensile strength and nearly as great ductility as the original metal. Fig. 12 (f) shows the fused metal in zone *5*. Experience indicates that the ductility of this section is considerably impaired, due probably to the presence of dissolved oxides, nitrides or even gases. Although the original metal has been subjected to a variety of heat treatments it may be safely concluded that, due to its low carbon content, its characteristics have been but slightly altered. To demonstrate this definitely, five standard tensile test pieces were prepared and arcs struck from four of them in such a manner that sections through the contact area exhibited the same transformations as are indicated in Fig. 12. The results of the test are shown in Fig. 13. Test piece *5* was used as the control, no arc having been drawn from it. The arcs drawn from *1* and *2* were supplied from a constant current system and those from *3* and *4* from a constant potential system. It may be noted that *3* broke a considerable distance from the arcing point thus serving as a check on test piece *5*. The tensile strength and elongation of all five pieces checked as closely as can be expected from different samples of the same stock and the effect of the thermal treatment on the physical characteristics appears to be negligible.

SUMMARY

In this brief exposition of the more apparent arc phenomena it has been the endeavor to show that:—



1 2 3 4 5

FIG. 13 NEGLIGIBLE EFFECT OF STRIKING AN ARC
On the physical characteristics of mild steel.

TEST PIECE	1	2	3	4	5
Ultimate Tensile Strength —Lbs. per Sq. In.......	49200	49100	48400	48600	49350
Percent Elongation	43	41.7	41.8	44	40

The maintenance of a short arc length and proper control of the arc flame insures minimum oxidation of the arc vapors and deposit surface, and therefore, reduces porosity and slag.

Weld scarf, arc current and arc manipulation are essential factors in the production of reliable welds.

The development of an electrode which generates a protecting envelope of inert, permanent gases will greatly facilitate arc welding.

The practice of examining test weld sections should be encouraged as a means of developing and indicating the operator's ability.

In passing through the arc stream, the electrode material is refined to such an extent that the deposited metal is comparable to commercially pure iron.

Thermal disturbances produced by the welding operation do not appear to affect appreciably the characteristics of mild steel welds.

Iron Commutators

B. G. Lamme
Chief Engineer
Westinghouse Electric & Mfg. Co.

During the past two years frequent inquiries have been made as to why iron is not used instead of copper in the construction of commutators. Obviously this question is inspired by rumors and statements that German manufacturers are using iron in commutators, due to the scarcity of copper since the outbreak of the war. Apparently also it has been assumed, in some instances, that the present use of copper is more or less of a fad and that other metals, such as iron, could be used if desired.

IN THE COURSE of the development of commutating machinery various metals have been tried out in commutators, all the way from pure copper, both hard and soft, through various alloys and brasses, cast copper of various purities, aluminum, wrought iron, clear down to cast iron. All such materials have received consideration at some time or other and have been given fairly conclusive tests. Experience has shown that all of them could be used in commutators if one is willing to pay the price, this price being in the first cost of apparatus, in maintenance or in less satisfactory operating characteristics, or a combination of all. Under the stress of war conditions it may be necessary to pay any price, and apparently this is the condition which has confronted German manufacturers. In consequence, materials and constructions are used simply as a matter of necessity which, however, may not conform to conditions of even reasonably good design.

The use of copper in modern commutators is a matter of development and not simply a fad. In fact, most of the early commutating machines used other metals in their commutators, which would now be considered quite unsuitable. Cast copper and various brasses and bronzes were used quite extensively, with more or less bad results. Pure copper was considered too expensive for general use and it was only after very considerable development that the conclusion was reached that its apparent higher first cost was more than neutralized by improved maintenance and operation. Even after pure copper had come into general use for commutator construction, it was not known, or understood, why it was so superior to other metals.

About twenty-seven years ago the writer made extended tests on the use of iron in street railway commutators. The machines soon developed "high mica" and the commutators gradually blackened, the contact surfaces blistered and sparking gradually increased until the commutating conditions became practically impossible from the operating standpoint. These conditions repeated themselves in every test until finally this construction was given up as impracticable. The difficulty was blamed largely upon high mica, as it was assumed that, in some way, the metal wore below the mica, thus causing bad brush contacts, with resultant burning and blackening. It was not recognized that the converse was really the case and that the high mica was the result of burning rather than the cause. In all machines of those days there was more or less tendency for the commutators to "wear" considerably, and it was not recognized that such was not true mechanical wear, but that it was the result of burning away the contact surfaces.

A little later, the writer made quite complete tests on the use of aluminum on street railway motor commutators. This material worked better than iron, in the sense that burning and blackening and high mica did not appear as quickly as with the iron. However, like the iron commutator, there was no tendency to polish, but the commutator soon assumed a dull appearance which gradually changed to a blackened and burnt condition.

Bronzes and brasses were tried on similar railway commutators, and while these gave better results than the aluminum or iron, yet they developed high mica much more quickly than the copper commutators. With such evidence at hand, the use of forged or drawn copper for commutator bars was a natural conclusion. However, even with the best copper obtainable, there was some tendency toward blackening and burning of the commutators, generally accompanied by high mica and the difficulty was blamed primarily on the mica. It was assumed that the copper bars did not wear as rapidly under the carbon brush as was the case with other metals. At the same time it was recognized that when the machine was operated without current none of these metals seemed to wear unduly. It was only when considerable current was carried that the wear was excessive. At that time, the real explanation of this difficulty was not fully appreciated.

Later investigations on collector rings and commutators, developed the fact that whenever a current is carried between a stationary brush contact and a moving surface, there is a tendency to burn away either the brush contact face or the moving surface, depending upon the direction of the current and upon the current density. It was found that this burning action, which is somewhat similar to that occurring in an arc, was to some extent a function of the contact loss. This was indicated partly by the fact that the burning was a function of both the brush contact drop and the current density. A given current, for instance, might produce very little burning as long as the contact drop was quite low; whereas, if for any reason such contact drop increased materially, noticeable burning would begin. If the current was from the brush to the commutator or collector, the brush contact surface would tend to burn away more than the opposing surface. If, on the contrary, the current was from the collector or commutator to the

brush, then the collector surfaces would tend to burn and, in some cases, deposit the burnt material on the brush face.

When carbon brushes are used, there is usually a very considerable contact drop due, apparently, to the nature of the materials in the brush itself. This drop, in many cases, is in the nature of one volt for each contact and it is fairly constant over quite a wide range of current. In consequence, the contact loss varies nearly in proportion to the current and not as the square of the current. Due to this very considerable loss with carbon brushes, there is a tendency to burn away the brush surface and to burn and blister the commutator or collector surfaces with which the brush is in contact. This tendency to burn is dependent upon the actual current density in the brush (including local or short-circuit currents), but the resultant burning is largely a function of the material in the commutator or collector face. As the brush cannot make perfect contact with the metallic surface to which it is opposed, there are minute arcs at the contact and these evidently burn away the surfaces. However, the real burning action is dependent upon the inability of the surface to conduct away heat rapidly, for if the heat developed in the surface film is not conducted away with sufficient rapidity, then such surface is liable to be blistered or burned locally, even though moving with respect to the brush. Such burning or blistering naturally roughens the contact surface and increases the contact drop and thus tends to increase the arcing and burning action. Thus, if there is any burning action it tends to grow worse, cumulatively. This burning away of the surface leaves the metal surface of the commutator slightly lower than the mica, unless the latter wears mechanically at the same rate that the commutator metal burns away. As this is not usually the case, high mica soon develops, simply by the action of burning away of the metal. Thus high mica is a result of the trouble, rather than the cause. However, as even a very gradual burning away will eventually leave the mica above the surface, modern practice has tended toward undercutting of the mica, so that even with a slight burning tendency the brush still maintains contact with the metal, thus preventing accentuation of the trouble.

As mentioned before, this burning action is a function of the contact voltage, the current density and the non-burning or non-blistering qualities of the metal constituting the commutator. It is in this latter feature that copper has proven so superior to other metals. Extended experience shows that the heat conducting qualities of pure copper are so good compared with most other metals or alloys that the burning or blistering action of the current under the brush is very small, except for high current densities. Anything which tends to decrease the heat conducting properties of the commutator metal, tends to increase burning action. This has been very clearly demonstrated in elaborate tests of carbon brushes on collector rings, etc., where questions of commutation did not come in to disturb the conclusions. Such tests have been made covering copper, bronzes and alloys of various sorts, wrought iron, cast iron, etc. In practically all cases, with high current densities, the burning and blistering action appears to be dependent upon the ability to conduct the heat away from the contact surface. By such conduction the local heating of the contact film of metal is kept at a low point which results in reduced fusion of the metal, and with very good heat conducting materials the fusion of the metal may be so minute that the polishing action of the brush keeps the surface in a smooth glossy condition.

It is an interesting fact that the electrical conductivities of the metals and their mixtures and alloys, bear a fairly close relation to their heat conductivities. Experience shows that very little impurity in copper will reduce its electrical conductivity to possibly one-third or one-quarter, and its heat conductivity will be decreased nearly in proportion. Most of the alloys of copper have a very low conductivity compared with copper itself, while wrought iron is worse than most of the copper alloys in this regard. The series of tests above referred to, indicated quite clearly that the burning tendency varied very much as the electrical resistance of the material, that is, with the heat resistance. Wrought iron, having from eight to ten times the resistance of copper, would burn or blister and get rough at very much lower current densities than copper commutators or rings. Even some of the alloys which appeared to be good for collector rings, showed blistering effects at very much lower limiting current densities than copper. Consequently, it developed that the limiting carrying capacity of different metals in commutators and collector rings, varied roughly with the heat conducting qualities, and thus copper proved to be superior to any of its alloys or any other available material. According to this line of reasoning, silver should be better than copper, but this is not an available metal. The above also explains why alloys of copper in which other elements have been introduced for the purpose of hardening, etc., usually do not have the ultimate carrying capacity found in copper. Aluminum has fairly good heat conductivity, if pure, but it is so easily oxidized and the resistance of the oxidized surface rises so rapidly, that presumably this fact neutralizes any possible gain otherwise. Experience on actual commutators showed that aluminum did not take a polish, even under moderate current densities and, in fact, it acted very much like some of the higher resistance metals used in the tests.

It should be evident from the above that, when materials of higher heat resistance, that is, with poorer heat conductivity than copper, are used in commutators, the operating current densities should be reduced accordingly. Thus, it may be possible to use iron or steel for commutator bars, provided the brush current densities are reduced sufficiently. In very small machines, this might mean only an increase in the dimensions of the commutator and brushholders. In larger machines, however, any material modification in the proportion of the commutator may lead to radical changes in the machine as a whole, so that the total cost would be ma-

terially higher than in the copper commutator machine. This depends entirely upon how much sacrifice is to be made in operating conditions and maintenance. If these are to be kept at the same high standard as on present copper commutator machines, then it is questionable whether the iron commutator would prove to be practicable under any conditions. The same conditions hold true, to a certain extent, with certain alloys instead of copper in the commutator. As such alloys, as a rule, cost nearly as much as copper itself, it should be obvious that any material increase in the dimensions of a commutator will soon balance any possible gain.

In larger machines one serious condition would be liable to be encountered with other than copper commutators. At present these machines are built for quite high peripheral speeds of the commutators, and construction difficulties are encountered which would make any increase in their length or diameter very objectionable. Consequently, serious modifications in the general construction of the machine, and possibly in its speed conditions, are liable to be necessitated. In fact, in many cases the whole design of the machine is predicated on the commutator construction. In such cases the use of a poorer material in the commutator would undoubtedly be a backward step in the development.

It is thus obvious, that the use of iron in commutators, while possibly practicable under the urge of necessity, is not in the direction of an advance in the art. In fact, it is a big step backward. It should be assumed naturally that if, in the past thirty years of development in commutating machinery, iron commutators have not come to the front, it is for very good reasons, and the preceding is simply an attempt to bring out some of the foremost reasons.

Variation of Alternator Excitation with Load

F. D. Newbury

There are three primary factors that affect the amount of increased excitation required to maintain constant voltage of an alternator with increase of load: the magnetizing effect of the armature (or armature reaction), the reactance voltage of the armature and the resistance voltage of the armature. The effect of the last two, expressed in terms of exciting ampere-turns, is influenced greatly by the shape of the upper part of the saturation curve of the alternator. In considering this subject, the distinction between armature reaction and armature reactance is important; the lack of this has been responsible for considerable trouble in the past and a better appreciation of it by present-day designers has led to a marked improvement in alternator operation on low power-factor loads.

THERE are two principal fluxes in an alternator; the exciting field set up by the main field ampere-turns, and the modifying field set up by the armature ampere-turns. These two fluxes, of course, do not actually exist separately; they combine into one flux in parts of the magnetic circuit in which they both exist. However, not all of the field flux reaches the armature and not all of the armature flux reaches the field. That part of the flux, established by current in the armature winding, that does penetrate the field poles, that rotates with the field and combines with the main field flux, is called the *armature reaction.** The so-called "leakage" flux, set up by the armature current, that does not penetrate the field poles, i. e. the flux across the armature slots, from slot to slot across the air-gap and the flux surrounding the armature coil ends projecting from the core constitutes the flux of *armature reactance.* The greater part of this reactance flux exists independently of the main exciting flux and its effect is to reduce the internal voltage generated in the armature, in other words to use up part of the generated armature voltage. Another, but minor, part of the reactance flux—the leakage flux from tooth tip to tooth tip, for example—combines physically with the main flux in the air-gap. Whether this flux should be treated, in its effects, as a flux or as a voltage, is debatable. In Fig. 1, c is the flux of armature reaction, and a is the flux of armature reactance, while b may be one or the other. Practically, the important point is to separate the combined effects caused by current in the armature, and defined as armature reaction and armature reactance, into two parts; one whose effect on the excitation is independent of the terminal voltage, called *armature reaction,* and the other, *armature reactance,* whose effect on the excitation is dependent on the terminal voltage on account of magnetic saturation.

Armature reaction, thus defined, is a flux that combines with the main field flux and its presence in the alternator does not involve the generation of voltage;

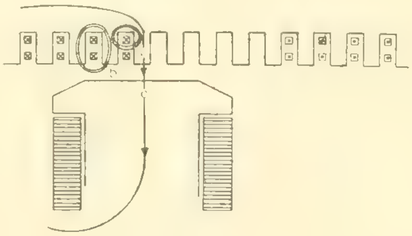


FIG. 1

therefore, its effect on the excitation is the same at zero voltage, with the armature short-circuited, as it is at normal voltage and zero power-factor.

The armature reactance, on the other hand, is a voltage which must be counterbalanced by the generation of additional voltage in the armature. It therefore affects the main field excitation by an amount that varies with the terminal voltage desired.

The effects on excitation of these factors can be investigated best by means of vector diagrams of the various voltages and fluxes involved.

At no-load the terminal and internal voltages E_T and E_I, Fig. 2, are identical, and the main exciting flux

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*This article should be read as a continuation of the author's contribution on "Armature Reaction of Polyphase Alternators," in the April issue of the Journal.

MF is 90 degrees ahead of the voltage. The voltage represented in the diagram is, of course, the voltage of one phase of the armature winding and the flux shown is the flux enclosed by the armature phase chosen. The length of this vector is proportional to the strength of the constant direct-current field (the maximum value of the enclosed flux) but the phase position of the vector is such that its projection on the vertical is the enclosed flux at the particular instant of time. Thus, at the time represented by Fig. 2, the voltage is a maximum, and the flux enclosed by the coil is zero. One-quarter cycle later the voltage will be zero, and the flux will be a maximum and equal to the total direct-current flux. These relations will be made clear by Fig. 3, in which *AA'* represents the armature phase to which the vectors of Fig. 2 apply. In the position of the rotor shown, the no-load voltage has its maximum value and the main exciting flux enclosed by the armature phase is zero. If the armature winding were two-phase, the voltage and flux vectors of phase *BB'* would be the same as in Fig. 2, except that the diagram would have to be rotated 90 degrees, that is, the voltage is zero and the flux enclosed by the phase is a maximum and equal to the total field strength.

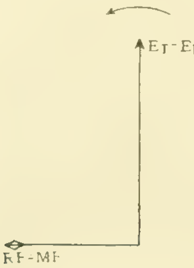

FIG. 2

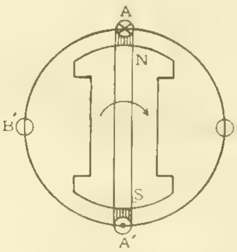

FIG. 3

In Fig. 4, the voltage and flux conditions under load are illustrated. The load current *I* is in phase with the terminal voltage E_T, which has the same value as in Fig. 2. The total internal voltage E_I combines with *IZ*, which is made up of the voltages of self-induction *IX* and of resistance *IR*, to produce the terminal voltage, E_T. Under these assumptions, the voltage *IR* is in phase opposition to the current and the voltage *IX* is 90 degrees behind the current.

The same results could have been obtained by considering the internal voltage E_I as the resultant of the terminal voltage and the voltage used in overcoming the voltages of resistance and reactance. In this case *IZ* would have the opposite direction, as shown by the dotted line. The resultant flux in the air-gap *RF* that produces the voltage E_I is 90 degrees ahead of the voltage it produces. Here also the flux vector represents the component of resultant or air-gap flux enclosed by the armature coils of the chosen phase. The length of the vector representing the resultant flux is determined from the value of internal voltage E_I and the corresponding ampere-turns taken from the saturation curve of the generator. The flux of armature reaction *AF* is in phase with the current as shown. The armature reaction, although produced by alternating current, is a continuous field fixed in space with respect to the main exciting field. The vector representing armature reaction, as with the other flux vectors, is the flux of armature reaction enclosed by the coils of the armature phase under consideration. That this enclosed flux has a maximum value equal to the total armature reaction and that it varies proportionally to the armature current in the chosen phase at all times, follow from the nature of armature reaction. In the case of a two-phase winding, these relations are self-evident, since the phases are at right angles (electrically) and the flux enclosed by either phase is due to the current in that phase alone. In a three-phase winding, all of the phases contribute to the flux enclosed by any one phase, but the sum of these fluxes is proportional to the current in the phase at all times.*

The meaning of the vectors representing fluxes has been gone into in detail, so that the physical meaning of the vectors will not be lost, and the significance of vectors representing alternator fluxes will be understood.

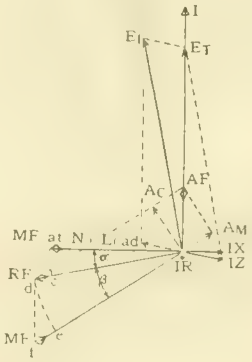

FIG. 4

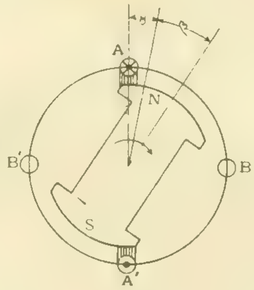

FIG. 5

The length of the vector representing armature reaction is determined by calculation from the alternator design, and is expressed in terms of main field ampere-turns. It may be determined experimentally by operating an alternator with its terminals short-circuited, and measuring the field ampere-turns necessary to circulate full-load current in the armature. These field ampere-turns are equivalent to the ampere-turns of armature reaction and to the field ampere-turns necessary to generate a voltage equal to the armature reactance and resistance drops. The ratio of the field current required to generate rated voltage at no load, to the field current required to circulate rated armature current with zero terminal voltage, is called the "short-circuit ratio." It is a convenient measure of the relative strength of the field and armature windings.

With two of the flux vectors, *AF* and *RF*, Fig. 4, known in amount and position, it is possible to determine the third—the main exciting flux *MF* by completing the parallelogram as shown.

*Reference to Figs. 11 and 12, p. 108, in the JOURNAL for April, '18, will help to make these relations clear.

A comparison of Figs. 2 and 4, shows that the main exciting flux *MF* at no load (or exciting current to which the former is proportional) has been increased by an amount *cd* for which armature reactance and resistance are responsible, and by an amount *ef* for which armature reaction is responsible. At the same time the position of the main exciting flux vector has been advanced an angle α due to armature voltage drop and an additional angle β due to armature reaction.

It is some times stated that, at 100 percent power-factor, the armature reaction flux is entirely a "cross-magnetizing" flux; i. e. that it does not decrease the main flux but merely shifts it across the pole face. Fig. 4 shows this statement to be erroneous. The armature flux is at right angles to the main flux only as it exists at no load. Under load it has a considerable demagnetizing effect due to the shift in rotor position. The armature flux *AF* can be resolved into two components, the cross-magnetizing component A_C and the demagnetizing component A_M. It is not until the armature current has a considerable leading component that the armature flux ceases to have a demagnetizing component.

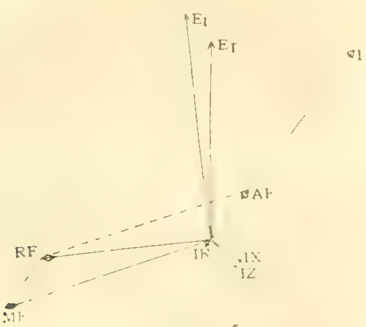

FIG. 6

The physical meaning of this change in position of the flux vectors can be seen by constructing Fig. 5, which bears the same relation to Fig. 4 as Fig. 3 bears to Fig. 2. It will be seen that the rotating part has changed its position so that when the terminal voltage is a maximum, the rotor is in advance (i. e., in the direction of rotation) of the position it had at no load. The direction of rotation of vectors is shown opposite to that of the actual rotor because the vectors refer to conditions of voltage and flux in the stationary armature. The angle of advance is the same as the angle of advance of the vector *MF* in Fig. 4, so that while the vector *MF* does not show the actual position of the rotor, the change in position of the vector is equal to the change in position of the rotor. The change in rotor position with changes in load and power-factor is of considerable importance in connection with the division of load between synchronous frequency changer sets, and in problems of synchronous motor operation.

Fig. 6 shows flux and voltage relations when the armature current lags behind the terminal voltage by an angle of 37 degrees corresponding to a power-factor of 80 percent. By this change in current position, the armature reactance voltage and reaction flux have been brought more nearly in opposition to the terminal voltage and the required air-gap flux, with the result that the internal voltage must be greater in order to maintain constant terminal voltage, and the main exciting flux must be increased by a still greater percentage. These effects are still more pronounced in Fig 7, in which the current lags behind the terminal voltage by 90 degrees. Here the armature impedance voltage almost entirely opposes the internal voltage and the armature reaction flux almost entirely opposes the main excitation.

Figs. 8 and 9 illustrate conditions when the current leads the terminal voltage. Fig. 8 illustrates the conditions when the armature reaction is practically neither magnetizing nor demagnetizing. It is not commonly recognized that, at 80 percent leading power-factor, the armature flux may still be demagnetizing, yet this is the case. With still greater leading components, the armature flux rapidly increases in magnetizing effect, until at zero leading power- factor it is, except for the negligible effect of armature resistance, entirely magnetizing.

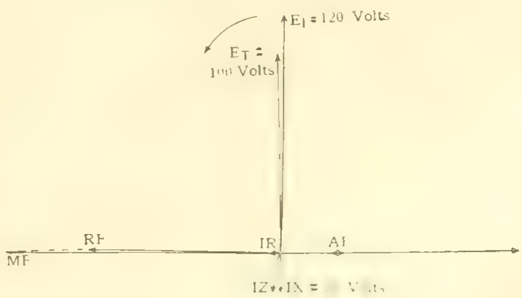

FIG. 7

These various vector diagrams correctly represent conditions only when the reluctance of the magnetic circuit is substantially the same at all points of the armature circumference. This is the case with a cylindrical turborotor but is obviously not the case with a salient pole rotor. The magnetizing effect of the armature current is determined experimentally by operating the generator at zero power-factor, i. e., when the armature flux is completely demagnetizing and the salient poles are in a position to produce minimum reluctance. This relation between armature flux and rotor position exists to a considerable degree at all lagging power-factors and at low leading power-factors, but at power-factors in the neighborhood of 80 percent leading (see Fig. 8) the armature flux has only a small magnetizing or demagnetizing effect and the rotor is in such a position with respect to the armature field that the magnetic reluctance is a maximum. Thus the value of armature flux determined experimentally is only applicable, in the salient pole alternator, under conditions of demagnetizing and magnetizing flux. All values of cross-flux component shown in the vector diagrams should be considerably reduced on account of the increased reluctance of the path the cross flux follows.

This correction is important only with the higher leading power-factors, a condition rarely encountered in practical work.

The diagrams, Figs. 2 to 9, are based on an actual generator design and are drawn to scale. The generator chosen has the no load saturation curve $A'A$ shown by Fig. 10. The magnitudes of the voltages and fluxes shown by the diagrams are given in Table I. This data for the condition of zero power-factor lagging is also indicated on the saturation curve $C'C$, Fig. 10. The internal voltage, at zero power-factor, is equal to the sum of the reactance voltage and the terminal voltage (neglecting the small resistance voltage). Thus AB is

FIG. 8

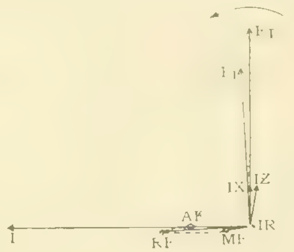

FIG. 9

the reactance voltage (20 percent of the terminal voltage) and BD is the terminal voltage. OD represents the resultant flux RF in field ampere-turns. Since at zero power-factor the value of the total existing ampere-turns MF is practically the sum of the resultant or air-gap ampere-turns, and the armature reaction ampere-turns, the total exciting ampere-turns may be shown on the saturation curve by adding the armature reaction BC to the resultant ampere-turns OD.

TABLE I—GENERATOR EXCITATION

Generator Data:—Short circuit ratio 1.5; Armature reaction 50 percent of no load field ampere turns; Armature reactance 20 percent of terminal voltage; Armature resistance 4 percent of terminal voltage.

Load Percent	P-F Percent	Term. Volts E_T	Internal Voltage E_I	Resultant Amp. Turns RF	Field Amp. Turns MF	Open-Circuit Voltage with Full Load A-T (Regulation)
0	-	1.00	1.00	1.00	1.00	1.00
100	100	1.00	1.06	1.12	1.28	1.16
100	80	1.00	1.15	1.34	1.70	1.25
100	0	1.00	1.20	1.51	2.00	1.31
100	0*	1.00	0.80	0.70	0.20	0.51

*Leading

In practical work, the following generator characteristics are determined from test:—

a—The no-load saturation curve, $A'A$.

b—The field ampere-turns required to circulate full-load armature current when the alternator is short-circuited. This gives the total ampere-turns necessary to overcome the armature voltage drop and the armature reaction. This point is indicated on the saturation curve at C' since the terminal voltage is zero.

c—The zero power-factor saturation curve $C'C$. This is obtained by using an under-excited generator as load.

There is no satisfactory way of determining the armature reaction and armature reactance separately by test. It is possible, however, to separate these two factors by a graphical method, based on the no-load and zero power-factor saturation curves. At all terminal voltages, the horizontal distance between the two saturation curves is made up of the ampere-turns required to generate a voltage equal to the armature drop (ampere-turns OB' for voltage $A'B'$) and the ampere-turns equivalent to the armature reaction (ampere-turns $B'C'$). Thus the points $A'C'$, of the right angled triangle $A'B'C'$, lie on the two saturation curves at all terminal voltages. By trial, it is possible to determine the dimensions of a triangle that best meets this condition and so determine the armature drop and armature reaction. This is, in effect, separating the combined effect of armature reaction and reactance on exciting current into two components; one, the reaction which is the same at all terminal voltages, and the other, the reactance which is dependent on terminal voltage, since it is a constant voltage $A'B'$ or AB that requires an increasingly greater exciting current OB' to GB for its generation as the terminal voltage is increased.

It is sometimes suggested that the armature reactance can be measured directly when the alternator rotor is at rest, or when the field is removed from the armature. A little consideration will make it clear that

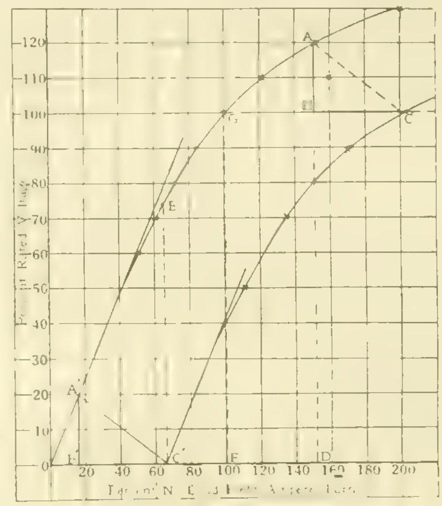

FIG. 10

the reactance measured with the field removed is that due to the total self-induction of the armature winding (fluxes a b and c of Fig. 1) modified by the increase in magnetic reluctance due to the removal of the field. This is considerably higher than the reactance during normal operation. With the field in position, but at rest, polyphase currents in the armature winding establish a rotating field that sets up an opposing field by currents in the rotor structure. Thus a part of the armature flux that penetrates the rotor (armature reaction) is neutralized so that the reactance, measured in this way, comes nearer the effective reactance of synchronous operation than does the reactance measured with the rotor removed. A low resistance cage winding, as used in single-phase generators, should improve this agreement. In general, the reactance measured with the rotor at rest (the locked saturation test commonly made on induction and synchronous motors) is somewhat higher than the reactance of synchronous operation.

The data in Table II, from tests on a single-phase generator give a quantitative idea of results from these several methods. The generator was provided with a complete three-phase winding and tests were made with the same current per terminal with both single-phase and polyphase current. The rotor had a low-resistance cage winding and the reactance measured with rotor at rest is in better agreement with the correct reactance than would otherwise be the case. The ratio between these various reactances will vary in other generators, due principally to differences in the shape and proportions of the generator parts, and it is not safe to draw conclusions from these figures other than those already indicated.

PRACTICAL EFFECTS OF POWER-FACTOR ON EXCITATION

The armature reaction and reactance have their greatest effect on excitation at zero power-factor. With lagging currents and zero power-factor, the armature reaction subtracts directly from the main excitation and the reactance voltage subtracts directly from the internal voltage. At other power-factors, armature reaction and reactance may be conveniently divided into a component oposing the excitation or internal voltage and a component at right angles to these quantities.

TABLE II—ARMATURE REACTANCES

Generator rating:—4500 k.v.a., 11 000 volts, single-phase, 25 cycles, 500 r.p.m.

Data from	Percentages at 4500 k.v.a. single phase	Percentages at 7800 k.v.a. three phase
Instantaneous short-circuit test..	13	10
No load and zero P-F sat. curves	13	11
Locked saturation test (rotor at rest)	15	12.5
Test without rotor in position ..	21	18
Synchronous reactance (reactance + reaction at zero terminal voltage, syn. speed)..	87	125

The opposing component of the reactance voltage is equal to the reactance voltage multiplied by the sine of the angle of phase difference between load current and terminal voltage; the component at right angles to this is equal to the total voltage multiplied by the cosine. Due to the shift in rotor position the two components of the reaction flux are not so simply determined but, as will be evident from Figs. 4 to 9, the demagnetizing component of the armature reaction decreases as the sine of the angle of phase difference decreases and the cross flux component increases as the cosine increases. Thus it is important to have a clear idea of the relative values of sines and cosines for different angles, as these represent the relative magnitudes of the reactive and power components of the current, and thus indicate roughly the effect of the load current on excitation. These relative values may be visualized by the triangles of Fig. 11. The important point to get from this illustration is the rapid increase in reactive or demagnetizing factor with relatively small variations in power-factor from 100 percent. Thus, with only one percent reduction in power-factor the reactive factor has increased to 14 percent of the total, and at 95 percent power-factor—still considered high by operating engineers—the demagnetizing effect is almost one-third as much as if the power-factor were zero. By changing the power-factor from 100 to 80 percent, the reactive factor has been increased to 60 percent of the total while an additional equal change in power-factor from 80 percent to 60 percent increases the reactive factor by only 20 points. The reason for this is made clear by plotting power-factor against reactive factor as in Fig. 12. The resulting curve is the quadrant of a circle. In the range from 80 to 60 percent power-factor, there is very nearly one percent change in reactive factor for one percent change in power-factor. For power-factors higher than 80, there is a gradually increasing ratio of change, and for power-factors below 60, there is a gradually decreasing ratio of change. For power-factors below 60 percent, the further increase in reactive factor has very little operating importance.

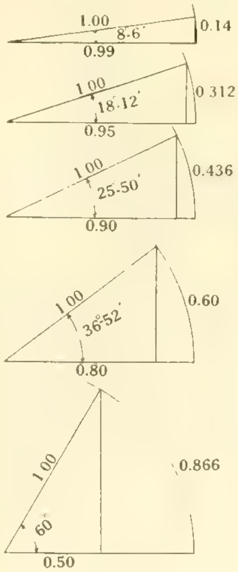

FIG. 11

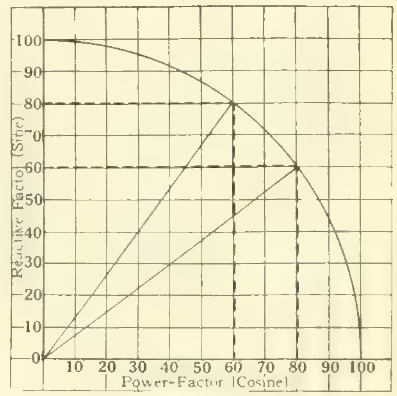

FIG. 12

The importance of these relations from the operator's point of view is that changes in power-factor of only a few percent with power-factors near 100 percent require large changes in exciting current to maintain constant bus-bar voltage, while large changes in power-factor, if the initial power-factor is lower than 60 percent, are usually unimportant.

Thus, it is unnecessary to determine very closely the power-factor of the starting current of induction or self-starting synchronous motors. It is sufficient to know that in all cases the power-factor is below 50 percent and the demagnetizing effect of this current is very nearly the same as it would be were the power-factor zero. On the other hand, if a large 25 cycle turbogenerator is intended to supply current exclusively to synchronous converters with a power-factor at the generator not lower than 95 percent, it is necessary to have a lively respect for the large increase in field current necessary to handle a general power or furnace load of even 85 or 80 percent power-factor.

Harmonic Analysis of Oscillograms

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THE most elementary consideration of alternating-current circuits involves the use of simple trigonometic functions to express the time variation of voltage and current. Usually this variation is expressed as a function of a single frequency, as $e = E \sin \omega t$, where e is the value of the electro-motive force at any instant; E, the maximum value of the wave; ω the angular velocity in radians per second for a two-pole machine and correspondingly smaller angles for multipolar machines; and t the time in seconds from the instant taken as zero time. The product ωt then is the angle in electrical degrees traversed from the reference time and is equal to $2 \pi f t$ where f is the frequency in cycles per second. Even when the variation of current or voltage is not simply a function of a single frequency, it has very often been used on account of the lack of means of obtaining the true mathematical statement of the variation of the function.

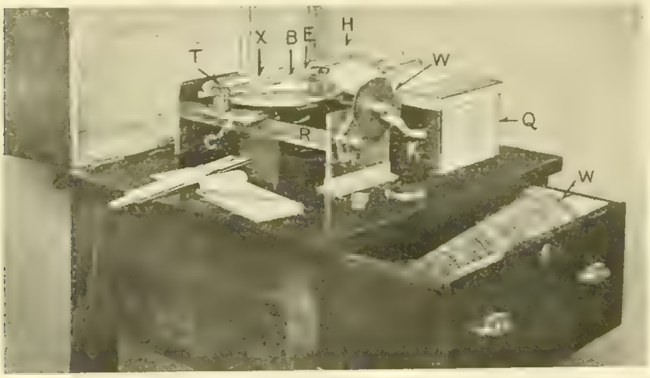

FIG. 1—HARMONIC ANALYZER

B—crossbar; C—carriage; E—contact point at edge of template; H—point of polar planimeter; K—handle; Q—card of gear ratios; R—slide rails; T—turntable; X—Template; W—gears.

An exact analysis of the variation of such a function can be obtained readily with the harmonic analyzer shown in Fig. 1 and the polar oscillograph attachments Fig. 2.* Experience in the practical operation of these devices has shown their usefulness in the simple but mathematically correct solution of all alternating-current problems, excepting transient phenomena. Erroneous conclusions can be avoided and the causes of electrical troubles can be found by the use of these appliances, which are so simple that a nontechnical man can obtain definite and accurate results.

As an illustration of the importance of harmonic solutions, take the determination of the potential drop and wave shape across an air reactance in series with an unloaded transformer. Assume a reasonable current-limiting reactance of 0.02 henries in series with a transformer rated at 1600 k.v.a., 25 cycles, 10 500 volts, which had an exciting current of 12.24 amperes at normal excitation; if it is further assumed that sufficient accuracy in the determination of the voltage drop across the reactor, will be obtained by expressing the exciting current as a function of a single frequency, as in curve A, Fig. 3, the wave shown by curve A of Fig. 4 will be that of the voltage drop across the reactor. The amplitude of this wave at any instant is proportional to the slope or tangent of the current wave at that instant; and the voltage is equal to the product of the inductance L, expressed in henries, and the time rate of change of current which expressed mathematically is:

$$e_L = L \frac{di}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where

$$i = -I \cos \omega t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The negative cosing function is used in place of the usual sine functions to give the proper phase relation with the impressed transformer voltage which is assumed to be xero at zero time. From equation (2)

$$\frac{di}{dt} = \omega I \sin \omega t \quad \ldots\ldots \quad (3)$$

Substituting this in equation (1)—,

$$e_L = \omega L I \sin \omega t \ldots \quad (4)$$

$$= 2 \pi 25 \times 0.02 \times \sqrt{2} \times 12.24 \sin 2 \pi 25 t = 54.4 \text{ volts} \ldots (5)$$

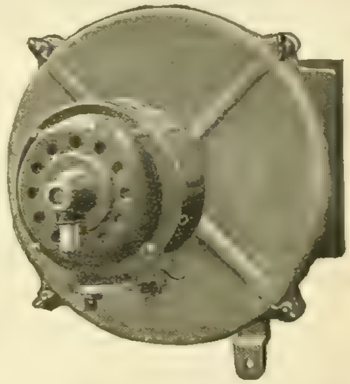

FIG. 2—POLAR OSCILLOGRAM FILM HOLDER

for the maximum value of curve A, Fig. 4, or 38.5 volts for the r.m.s. value obtained by omitting $\sqrt{2}$ from equation 5.

If, instead of this single frequency assumption, the more complete expression for the exciting current, the true shape of which is shown in curve B, Fig. 3, is found by methods described below to be

$$i = 0.665 \sin \omega t - 15.2 \cos \omega t - 0.272 \sin 3 \omega t - 7.91 \cos 3 \omega t \text{ etc.},$$

as given in Table I, the true shape and size of the voltage wave of the reactor will be that of curve B, Fig. 4.

The equation for this wave is given in tabulated form in Table II. It is determined in the same way that equation 4 was determined in the single frequency case, that is, by differentiating the current wave and multiplying by a constant. This is a very simple process, especially when the equations are tabulated, consisting simply of rewriting the A terms of the current wave under the B heading of the voltage wave and multiplying each by $2 \pi L$ and the order of the harmonic (e. g., by 5 for the fifth harmonic). The A or sine terms of the voltage wave are determined in the same way from the B or cosine terms of the current wave

*This analyzer was described and a theory of its operation given in articles by Mr. L. W. Chubb in the JOURNAL for February and May 1914, pp. 91 and 262.

except that the sign of each term must be changed. It will be noted how much more prominent the higher harmonics are in the differentiated wave due to being multiplied by the order of the harmonic.

This wave would give a reading of 68.1 volts on a voltmeter instead of 38.5 as calculated on the single frequency assumption. Then too, at the instant in the cycle when the time is 22 electrical degrees, with the above mentioned assumption, the amplitude would be calculated to be 21 volts while actually it would be 132 volts, and when the maximum value of the amplitude would be expected, the true amplitude would actually be very nearly zero.

A sine wave of voltage was used on the transformer when the exciting current was determined. In order to keep the above illustration simple the same wave shape was assumed on the terminals of the transformer, although in practice it is more than likely that this would be the wave shape on the power side of the reactance coil. The assumption just mentioned would not materially affect the lesson which may be gained from the example just given, from which it is readily seen how

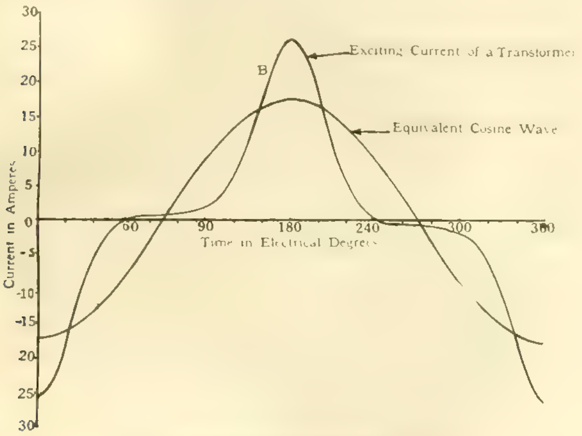

FIG. 3 TRANSFORMER WAVE SHAPES
B—Exciting current.
A—Equivalent cosine wave.

easily a misconception might be obtained as to what is occurring in a more complicated circuit in which the phenomena are not so well known.

To illustrate the method of determining the correct expressions for periodic waves by means of the apparatus mentioned earlier in this article, the operations involved will be described somewhat in detail, using a simple test on apparatus, the principle of operation of which is well known, namely; a three-phase, delta-connected transformer without load, the only unusual feature being that one phase winding of the transformer is off-ratio by one turn.

Polar oscillograms were taken of the phase voltage and the current of each leg of the delta winding, Fig. 5, using a circular film holder in connection with the ordinary oscillograph in the same manner as with the familiar rectangular film holder. The film was driven in synchronism by a self starting synchronous motor which comes up to speed in an instant, and is a great time saver compared to the stroboscopic method formerly used. The use of a synchronous film permits repeated exposures of the oscillogram and so a weaker light may be used, such as that from a nitrogen filled, concentrated filament lamp, arranged for over-voltage operation during the exposure of the film; replacing the arc light which required much more attention.

The leads from one element were touched successively to the terminals of each of the phases of the transformer under test, or the corresponding points on voltage transformers and in succession to the terminals of the oscillograph resistances in series with each phase, shown in Fig. 5. Meanwhile, the synchronous film motor was kept running and the film shutter was opened for approximately one-half second after each connection had been made. In this manner all the waves desired were shown in their proper phase position, and all on one film as shown in Fig. 6. When quite a number of waves are to be put on one film, it is best to use two or three elements at a time; say one for the voltage and one for the current, which will permit the use of the same calibration for all the waves of one kind.

After developing the film, the time-axis was put on by drawing a diameter through the zero circle, Fig. 6,

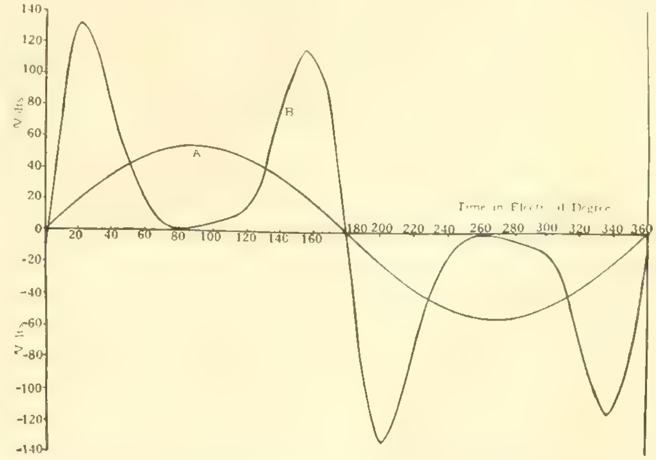

FIG. 4—VOLTAGE DROP ACROSS AN AIR CORE REACTOR OF 0.02 HENRIES
B—due to the exciting current wave B of Fig. 3.
A—due to the equivalent cosine wave A of Fig. 3.

at the point where phase *A* voltage wave passes through zero in the positive direction. The rotation of the film is always clockwise so that the progression of time is counter-clockwise to conform to the usual trigonometric conventions.

As many prints were made as there were waves to be analyzed, using solio paper stapled to six or eight ply bristol board of good quality. This card board, when cut to the shape of the wave on the solio print, forms the template used on the analyzer. Judging from a comparison of the results obtained by the analysis of other templates cut by different men from different films taken on the same phenomenon, it appears as though the outline of the template did not vary more than one or two hundredths of an inch. As a matter of fact, only ordinary care and ordinary shears were used in cutting the template but the results check very closely, probably because the variations from the correct shape do not occur at any definite frequency.

The use of a pattern print of solio paper does away

with the necessity for washing or developing the prints. These operations not only take time but might result in a greater shrinkage in one direction than in another. The time axis was quickly transferred from the print to the cardboard template by punching a couple of holes into the bristol board through the reference line on the print, with a pin or needle.

The bristol board templates of each wave thus made were used in conjunction with the analyzer, Fig. 1. The analysis consisted of finding the sine and cosine coefficients of each of the odd harmonic components up to the thirteenth. The eleventh harmonic was negligibly small and so was not recorded. When a number of waves are to be analyzed, the greatest speed can be obtained by determining both the *A* and *B* components* of each wave in turn for a given harmonic instead of completely analyzing each wave, which would involve an unnecessary amount of gear changing. Any coefficient is determined by placing the template *X*, Fig. 1, on the

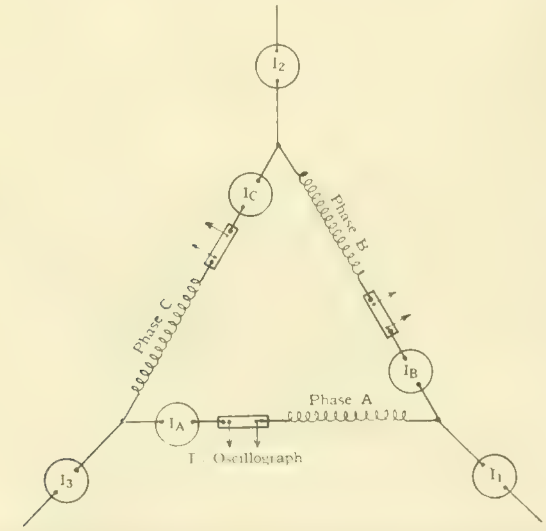

FIG. 5—TEST CONNECTIONS OF DELTA-CONNECTED TRANSFORMER

turntable *T* so that the time axis coincides with the corresponding mark on the instrument, turning the handle *K* to the right until the table makes one revolution, using the gears *W* specified in the chart *Q*, and noting the difference in the readings of the planimeter at the start and finish. The carriage *C* starts from the near end of the rails *R* for the sine coefficients or *A* terms and from the mid position on the rails for the cosine or *B* terms. The planimeter with its tracing point *H* set in one end of the bar *B* integrates an area which is proportional to the coefficient sought. The motion imparted to this tracing point is produced by the simple harmonic motion of the carriage back and forth on the rails and in the traverse direction by the rotation of the template attached to the turntable.

The actual operation of the analyzer is more simple than any complete description would indicate, as may be judged from the fact that a total of over 100 constants have been determined on six different templates in four hours after the templates were ready for use, by an operator who had little experience on the analyzer. By the mathematical or graphical methods formerly used, this would likely take many days, the accuracy would be less, and the work much more tiring. The analyses of the waves shown in Fig. 6 are given in Table III.

By "order of the harmonic", *n*, mentioned in the table, is meant the number by which the fundamental frequency must be multiplied to give the frequency of the wave whose order is *n*. For example: when $n = 5$ and the fundamental frequency of the circuit is 60, then the frequency corresponding to *n* is 5×60 or 300.

Any vector *C*, Fig. 7, can be compounded from two other vectors *A* and *B*, both of which have a phase position different from that of *C* and an angle of 90 degrees between them. The angle α is equal to $\tan^{-1} B/A$. In the same manner a harmonic wave

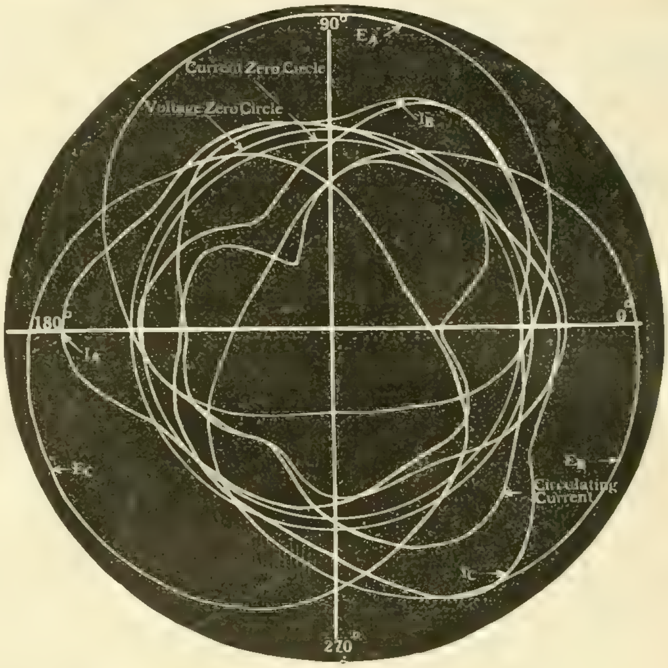

FIG. 6—POLAR OSCILLOGRAM

Of the vector relations in a delta-connected group of transformers, showing seven waves, three of voltage, three of exciting current and one of the circulating current, in addition to the zero circles.

$C \sin 3 (\omega + \alpha)$ can be found from two components, $A \sin 3\theta + B \cos \theta$, which are 90 degrees apart. In this case the value of *C* and α are determined in exactly the same manner as in the preceeding case.

If *A* is a positive number, it means that the sine wave passes through zero in the positive direction, as in Fig. 8; but, in a negative direction, if *A* is negative. If *B* has a positive sign the cosine wave has a positive maximum at zero time, as in Fig. 8; but if negative, it has a negative maximum at zero time.

According to Kirchoff's law, the sum of the line currents at any instant is zero; but if we take the sum of the equations of the currents in the three phase-windings we find that it is a considerable quantity, due to the current circulating in the delta circuit of the transformer. The algebraic sum of the currents in each of the three phase-windings divided by 3, shown in Table III, gives the equation of the circulating current.

*See article by L. W. Chubb, *loc. cit.*

The factor 3 must be used because the circulating current was included in each of the coil currents and so it has been included three times in the algebraic sum of those currents.

The terms of the equation for the circulating current determined directly from the circulating current wave of the oscillogram shown in Fig. 6 check fairly well with those of the equation obtained by taking one-third of the sum of the equations of the coil currents, while the r.m.s. value of current (4.29 amperes) of the two equations of circulating current check to less than 0.5 percent. This current was also measured by an ammeter which indicated the same value of current as was obtained from the equations. The measurements and the oscillograms of this current were obtained with one of the primary coils of three current transformers in series with each phase-winding; and the three secondary coils in parallel across an ammeter and oscillograph shunt as shown in Fig. 9. The symmetrical components of the line currents in the three delta connected windings cancel, because of their three-phase relation, and a current proportional only to the circulating current will flow in the ammeter. The ammeter reading, multiplied by the ratio of the current transformer, must be divided by three for the same reason given above for dividing the three Fourier's series by three.

FIG. 7—SUMMATION OF VECTORS

The circulating current generally consists mainly of a third harmonic, that is, of a sinusoidal wave of three times nominal frequency of the circuit. However, in this case there was a large circulating current of the fundamental or the nominal frequency of the circuit. This suggested that the ratio was incorrect in one phase, which later was proven to be true. This accounts for the peculiar shape of the exciting current waves.

With the equation of the waves available almost any of their properties can be obtained. For example; the r.m.s. value is the square root of one-half the sum of the squares of the A and B coefficients of all the harmonics. For the r.m.s. current in phase A:—

$$I_A = \sqrt{0.5(0.84^2 + 16.48^2 + 1.14^2 + 5.90^2 + 0.51^2 + 5.40^2 + \cdots + 0.31^2)}$$
$$= 13.92 \text{ amperes.}$$

The amplitude of any wave at $\theta = 0$, that is, when phase A voltage, which was used as the time reference in this analysis, crosses through zero in the positive direction, is equal to the algebraic sum of all the B coefficients. A quarter of a cycle later, the amplitude of any wave is the sum of all the A coefficients.

The power is one-half the algebraic sum of the products of the coefficients of the voltage wave into the corresponding terms of the current wave. The power, for example, delivered to phase A at fundamental frequency is:

$$P_{1A} = 0.5\ (6.84 \times 10\,270 + 16.48 \times 314) = 37\,713 \text{ watts.}$$

In the same way the third harmonic delivers 147 watts; the fifth, 150; and the seventh, 372 watts. In other words, all the power which is consumed in the losses of this transformer enters at nominal frequency while a part of the power received at this frequency is transformed to power at higher frequency, which, in this case, is being returned to the line. In the same way

TABLE I—EQUATION OF EXCITING CURRENT OF A TRANSFORMER, IN AMPERES.

Order of the Harmonic, N	Corresponding Frequency Cycles per Sec.	Coefficient of Sine Terms, A_n	Coefficient of Cosine Terms B_n
1	25	+.655	—15.20
3	75	—.272	— 7.91
5	125	—.315	— 2.34
7	175	—.117	— 0.39
9	225	—.081	— 0.11

TABLE II—EQUATION OF VOLTAGE DROP ACROSS AN INDUCTANCE OF 0.02 HENRIES.

Produced by the Exciting Current given in Table I.

Order of the Harmonic, N	Corresponding Frequency Cycles per Sec.	Coefficient of Sine Terms, A_n	Coefficient of Cosine Terms, B_n
1	25	+47.7	+2.09
3	75	+74.4	-2.56
5	125	+36.8	—4.95
7	175	+ 8.57	—2.57
9	225	+ 3.10	—2.29

the power delivered to phases B and C is 25 117 and 18 665 watts respectively. The fact that phase C received a negative amount of power was due to the transformer being off ratio. The total net power determined in this way was between two check determinations made with wattmeters.

The difference of the equations for the current in phases A and B will give the current in line AB. The current in line AB determined in this way was 2.74 amperes and the corresponding ammeter reading was 2.81 amperes. The other r.m.s. values determined from the equations checked the meter equally well.

Since the equation of voltage is known, the flux wave may be determined from $\Phi = K \int \frac{de}{dt}$. The value of K may be obtained from the design data. It consists of such factors as the number of turns on which the voltage is impressed, and the frequency of the supply circuit.

The angle of phase difference between any two waves may be found, if desired, from the fact that the phase angle of any wave with respect to the reference

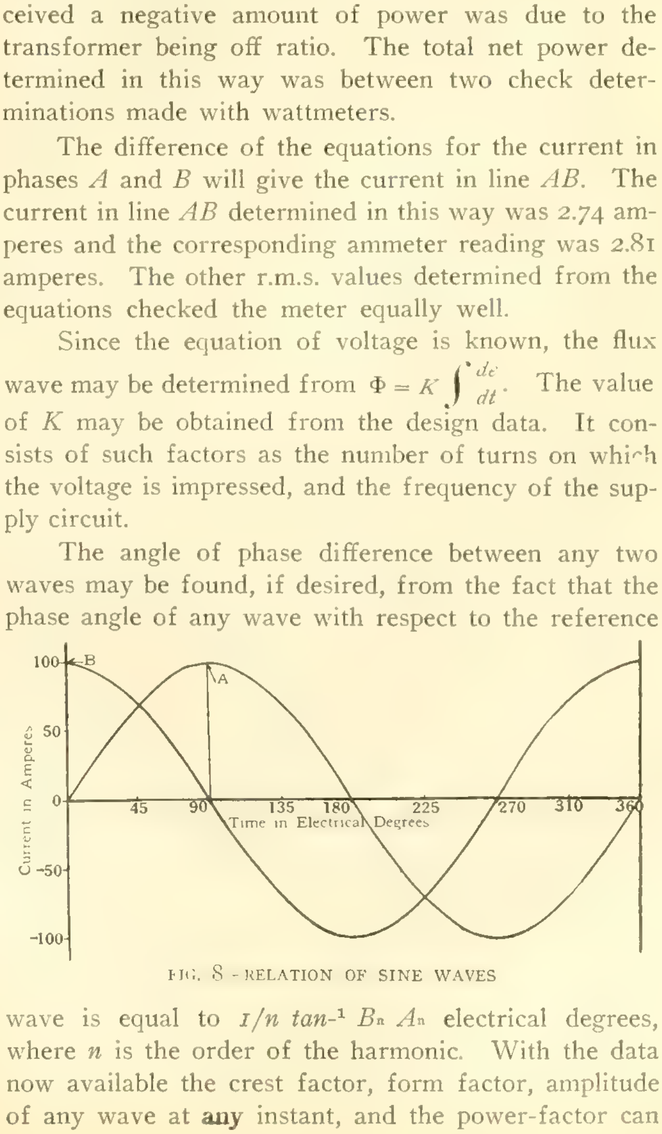

FIG. 8—RELATION OF SINE WAVES

wave is equal to $1/n \tan^{-1} B_n / A_n$ electrical degrees, where n is the order of the harmonic. With the data now available the crest factor, form factor, amplitude of any wave at any instant, and the power-factor can

be obtained. This example gives an idea of how well the data determined from oscillograms will check the power and r.m.s. meters, determinations of voltage and current, and also of the amount of information which the meters will not give that can be obtained by using analyzed oscillograms.

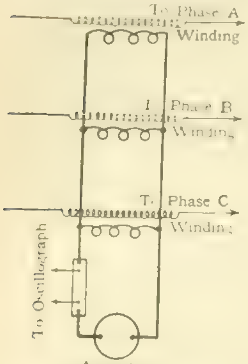

FIG. 9—TEST CONNECTIONS

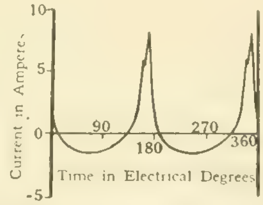

FIG. 10—SECONDARY CURRENT WAVE OF A SINGLE-PHASE INDUCTION MOTOR

The polar oscillogram attachment and the harmonic analyzer will be of most value in settling points of doubt concerning phenomena which are not as well understood as is the preceeding example. They are not limited to phenomena of odd frequency but can determine even or odd harmonics of a wave up to the fiftieth harmonic. A practical case where large even harmonics occur is in the secondary current of a single-phase induction motor having a wave shape shown by a rectangular oscillogram in Fig. 10. The analysis of the polar oscillogram of the same wave shows that it consisted of a fundamental equal to four percent of the equivalent sine wave, 80 percent of second harmonic, 45 percent of fourth harmonic, 31 percent of sixth, 21 percent of eighth and 15 percent of tenth. These percentages express the proportion each harmonic is of the equivalent sine wave. It appears that the sum of these components is greater than 100 percent, but harmonics are added by taking the square root of the sum of the squares of the various harmonics.

Harmonic analysis has been very useful in locating transformer trouble and doubtless could be used to great advantage on other apparatus. A harmonic analysis has been made of the exciting current corresponding to various inductions at which a power transformer might operate. This analysis is now used as a standard for comparison as the transformer used in compiling the data of the harmonic's components at various inductions was normal in all respects.

Now, if another transformer shows abnormal characteristics, a comparison of its analysis with that of the standard analysis will often locate the trouble. For example: if all the higher harmonics are a larger percentage of the fundamental than the percentages determined from the standard analysis at an induction equal to that of the calculated value of the transformer under test, it is likely that the core contains an amount of iron which is too small to permit it to operate at its calculated induction. If the total exciting current of a butt-joint transformer is high and yet the higher harmonics are small, it is probable that the assembly of the core has resulted in air gaps at the joints of the laminations, which would increase the fundamental without affecting the higher harmonics.

If the A_1, A_5 and A_9 coefficients are large and the A_3, A_7 and A_{11} coefficients have a comparatively small positive value (analyzed from the positive zero value of the voltage wave), a large coercive force and correspondingly high core loss is probable, and may be due to poor annealing. Of course, the problem is more difficult if several of these factors enter at once.

With normal transformers, it is rather remarkable how closely the percent values of higher harmonics of exciting current will check, when operating at the same induction, even though the designs be quite different. For example: single-phase transformers usually have a third harmonic of approximately 23 percent at an induction of 6000 gausses, 39 percent at 10 000 and 55 percent at 16 000 gausses.

Harmonic analysis by means of polar films and the mechanical analyzer is also useful in the determination of the reason a generator interferes with telephone and telegraph service. Knowing which harmonics are the source of the trouble, the design of the machine may be changed to eliminate the cause of these harmonics.

TABLE III—HARMONIC EQUATIONS OF VOLTAGE, EXCITING CURRENT AND CIRCULATING CURRENT

Of a Three-Phase, Off-Ratio Transformer. Amplitudes in Volts and Amperes.

		1	3	5	7	9
Coefficient of Sine Terms, A_n	Current in Phase A	+6.84	+1.14	—.51	+0.31	—0.08
	Current in Phase B	+11.86	—.37	—3.55	+1.28	—0.07
	Current in Phase C	—20.40	+1.05	+4.40	—2.02	—0.24
Coefficient of Cosine Terms, B_n	Current in Phase A	—16.48	—5.90	—5.46	—2.04	—0.31
	Current in Phase B	+11.73	+.95	+2.08	+0.26	+0.04
	Current in Phase C	+16.72	+8.31	+4.84	+1.46	—0.48
Coefficient of Sine Terms, A_n	Voltage of Phase A	+10 270	—129	—295	—120	—18
	Voltage of Phase B	—4 760	—103	+263	[illegible]	+19
	Voltage of Phase C	—5 410	—110	+64	+101	+9
Coefficient of Cosine Terms, B_n	Voltage of Phase A	—314	+111	+166	+9	0
	Voltage of Phase B	+9 140	+9	+170	—85	0
	Voltage of Phase C	—8 730	+27	—310	+55	+18
Coefficient of Sine Terms, A_n	Circulating Current	+0.25	+0.48	+0.08	+0.04	—0.22
Coefficient of Cosine Terms, B_n	Circulating Current	+4.06	—4.46	+0.23	+0.05	—0.32
Coefficient of Sine Terms, A_n	One third of the algebraic sum of the	—0.57	+0.61	+0.11	—0.14	—0.13
Coefficient of Cosine Terms, B_n	current in phase A B and C	+3.99	—4.42	+0.49	—0.11	—0.25

Some of the advantages of the polar oscillograms maybe summarized as follows:—

a—The ease with which the correct mathematical expression for a periodic wave can be obtained.

b—The large scale on which a wave is taken; for example, the length of the phase *C* current wave of Fig. 6 is 50 cm. (20 inches) while the length of a single-cycle in a rectangular oscillogram is usually 10 cm. or less, due to the fact that if the film is run faster to produce a greater length for a given cycle along the time axis, the exposure is not sufficient to make a clear line on the film. In polar coordinates this line is usually traced over several times as the film rotates synchronously.

c—The ease of obtaining the constants of the analyzed wave such as the r.m.s., average and maximum values, the form factor, etc.

d—The fact that many waves can be taken on a single film and their proper phase relation will be shown. This also reduces the number of films required to a minimum and saves the time of loading and developing. For example, to show the seven waves recorded on one polar film (Fig. 5), and a reference vector so that the phase relation could be determined, a 3-element rectangular oscillograph would require four films.

e—The power can be measured in circuits having a very abnormal wave shape and in which the period required for the determination of the power of these peculiar waves may be short, or the power-factor unusually low.

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Superintendent,
The Beaver Valley Pa. Traction Company

In response to an inquiry from a business and personal friend, Mr. W. H. Boyce explains in the following letter a policy of winning the public's confidence, goodwill, and support, that is well worth the consideration of all street railway managements, and especially of those in cities of moderate size who are apt to feel that such a policy is warranted only by companies serving larger communities.

The sample advertisements represent only a few selected from the large number used by Mr. Boyce in the last six years. When asked to select those advertisements which were productive of the best results, Mr. Boyce replied: "I hardly know what to say, for in my opinion hardly any of these advertisements would stand alone and be of much benefit. It is getting to the people from the many different angles that has counted." (Ed.)

My Dear Mr. ....:—

Replying more fully to yours of the 12th inst., I'll attempt to answer the questions in the order you put them to me.

First—What prompted me to start a campaign of this sort?

Second—What was the feeling of the public before such a campaign was started?

Third—What is the attitude of the public since the facts have been put before them in such a light?

Fourth—What were the results obtained?

1—In the fall of 1912 I first fully realized the need of acquainting the public with at least some of the many of our operating problems. This, too, came at a time when the relations existing between the company and the owners and editors of the three daily and two weekly papers were maintaining a fair attitude. The newspaper men were beginning to realize through the media of matters of mutual interest discussed during my many visits at their offices and their friendly calls upon me, that all we asked for was a square deal and that we had nothing to hide; that the star chamber sessions and back door hand-outs, if they had ever existed, were a thing of the past; that all we asked from them or any person was an even break; that in a measure a community could only prosper to the extent that the public utilities of that vicinity prospered. Yet, there was much to be desired.

News articles which we furnished the newspapers, and which they ran, upon the operation of our store room, the lost article department, methods used in combating snow, employees' outings, etc., after a time, it seemed to me, reacted in a measure upon both the newspapers and ourselves. I have had persons say to me: "What did it cost you to have that article placed in the ....?"

The conclusion was obvious—Do like any other up-to-date business concern. Contract for a certain amount of paid advertising space and properly use that space.

The question then was what to advertise first. Naturally it must be something in which we could interest the general

NO POWER

Delay to cars was the result of a series of small mishaps which in the aggregate caused a delay of almost 45 minutes.

The primary cause for the delay to the cars Thursday was that the condenser pumps failed by reason of sticks, weeds, etc., being sucked up from the river. This in turn put out of commission our vacuum system which draws the oil to the top of the engine room, from which point it is fed to the engines.

Due to our inexperience in handling the new rotary which we have just put into use and which was pulling part of the load after we had to pull off our engines on account of lack o foil, it reversed the generators of each of these engines when we did get them running and attempted to make them take part of the load. The polarity of these generators then had to be reversed again. Each of these delays, small in themselves, totaled 45 minutes.

The Beaver Valley Traction Co.

THAT BLUE FLAG OF THE WEATHER BUREAU

When the Blue Flag is displayed at the Weather Station it means

RAIN or SNOW

If the latter, it costs this Company hundreds and sometimes thousands of dollars.
Sweepers must be equipped and ready. Bearings of all equipment examined and oiled.
Extra crews must be on duty before the snow gets so deep that it is evident the sweepers must be sent out.
When snow starts to fall, we cannot wait until we determine the depth of the fall before we commence our fight against it.
Many nights when snow threatens, [illegible] to 10 trainmen are kept on duty at full pay for this emergency.
Of course this is protecting our earning capacity, but we just want to call your attention to another of the many strains upon the nickel.

The Beaver Valley Traction Co.

It's Pretty Soft for You

YOU HAVE A SOLDIER IN FRANCE WHO IS FACING DEATH FOR YOU. What can you do for him? There is very little that you can do for him in comparison to what he is doing for you. BUT—

You can give him yourself—your loyalty in thought, work and deed. You can give him your money—to the last dollar if he needs it to carry on your fight.

But your country does not ask you to give, only to invest your savings in the best and safest bond on earth—the Liberty Bond. It's pretty soft for you, isn't it?

Buy your bonds today that your soldier in France may know that the man for whom he is going through Hell has fighting stuff in him, even if he has to stay at home.

Inserted by

The Beaver Valley Traction Co.

public. Accident prevention was the opening gun. On Saturday, December 7th, 1912, all the daily papers ran a first page story, dealing in a general way with the number of accidents happening yearly in the United States. They dwelt on the terrific economic waste of such a large number of preventable accidents and announced to the public that this Company would on Monday, December 9th, 1912, start an advertising campaign in an attempt to educate the public to the dangers of the street.

We started off with a full page advertisement. This ran for three days. Then a half-page advertisement was run for three days. Then we cut the space to that contracted for on a yearly basis, a 10-inch single column, or 5-inch double column per day. Since that time we have kept continuously at it in one form or another, *i.e.*, accident prevention advertising, public relations advertising, traffic promotion advertising or advertising in behalf of some worthy project, such as for the past three weeks, we have devoted our space continuously to the promotion of the sale of bonds of the Third Liberty Loan.

Why We Are Going To Appeal To You

[illegible]

UNDOUBTEDLY CONDEMNING A SERVICE DOES NOT AID IN ANY WAY IN BRINGING ABOUT A BETTERMENT

WE HAVE NO OBJECTION IF AT PRESENT YOU DO CONDEMN THE SERVICE IF YOU WILL ACCORD US THE FAIRNESS OF READING EACH ONE OF OUR ADVERTISEMENTS

[illegible]

The Beaver Valley Traction Co.
W. H. BOYCE, Superintendent

I have been criticised by some for the homely English of which some of our advertisements are composed. Have had other operators say: "That's all very well for a small community like the Beaver Valley, but for a Company our size, your type of advertisements is not dignified enough." But our advertisements have been written with a view to reaching the masses; the classes as a rule are not inclined to be so antagonistic.

We must not take ourselves too seriously even in advertising. Lincoln "got by" even though he did enjoy a joke. Billy Sunday has been *fairly* successful, though not too choice in his use of the English language. We have had more favorable comment on such advertisements as: "Is Your House in Order?" than on those of greater dignity.

The one fixed principle governing our advertising matter, is that we shall not maintain one attitude toward the public in our advertising and permit the trainmen or other employees to assume another; nor do we maintain any policy in print and in reality practice another. We have shown defects in our service in paid advertising, promising a remedy if that were possible; if not, showing why not. We have had a great deal more satisfaction from this criticism of our own, than to have had others portray our shortcomings in language warped to their own ends.

2—As to your second question—Now, I hate to believe it, but if they really meant all they said and wrote during those times, our public must have been feeling rather badly about their real and fancied wrongs. Enough of this reply to your Question No. 2. I hasten to the more pleasant third.

3—The next time you call upon me, I will take pleasure in exhibiting to you some very flattering, to me, published "Letters to the Editor," the origin of which I assure you I had no hand in or previous knowledge of. You probably know how those things are accomplished sometimes. Honestly, at times, especially this past winter, the public here has put up with a great deal and said very little. Why? Because they

Lest We Forget

"Safety First"

Every ounce of strength and energy of the American people at home must be diverted into the proper channels if our military forces are to be fully supported.

Carelessness and Negligence will not help

Every Accident reduces the Efficiency of Our Nation

Let us do all we possibly can to promote the cause of SAFETY FIRST

The Beaver Valley Traction Co.
W. H. BOYCE, Superintendent

Is Your House in Order?

Does the maid always do as she is told
Does the wife always [illegible]?
Do the children ever get [illegible]?
Does the furnace ever smoke?
Do the spigots leak
Does the landlord always promptly make the requested repairs?
Does the newsboy ever fail to leave your paper?
Does the dinner always suit you
Does every little thing always go just right at your house?

Our system is just a great big wonderful house, wonderful in that so many things do go right

THE BEAVER VALLEY TRACTION CO.

now know that we are not voluntarily going to reduce our service 50 percent, when by that reduction the loss to us means hundreds of dollars. They now know how difficult it is to heat a street car during zero weather, because they know how difficult it is to heat a house during cold, windy weather and we have pointed out to them how much greater the task would be, if the house had windows on all sides instead of brick or weatherboarding, the doors of the house being constantly opened and closed, and the house propelled rapidly through space, or placed on an exposed location with a thirty mile wind blowing.

There were a great many similar things that they knew before, but hadn't taken the trouble to compare the conditions which affected their business and home life to the street rail-

ways. We have gone along on the theory that a great many persons like to, and do think, after reading an article that they have known the fundamental facts contained in the article for a long time, but had never had occasion to paraphrase or associate them as they were used in the article read. We have applied this theory to some of our advertising. We gladly record that there has been a decided betterment of the attitude of the public.

TIMES PAST AND PRESENT

For the first three months of this fiscal year—that is, April May and June, 1917, our Gross Revenues increased $7,790 23 For the same three months our Total Street Railway Operating Expenses and Taxes increased $16,809 16

The [illegible] in the Electric Railway business [illegible] the prosperity of every person, and the [illegible] of every borough in this [illegible] very directly You do not have to be a [illegible] man or woman to understand that [illegible] can continue at a loss, nor with inadequate resources If its expenses go up beyond a certain point, its income must go up too

On July 21st the New Jersey commission allowed the North Jersey Co to increase their rate from 5c to 6c Why not? The baker is charging 10c for the loaf they used to sell for 5c because it costs them more. "The watch that made the dollar famous" is now sold for $1.35 for the same reason. "Uncle Sam" is even going to raise the price of postage stamps from 2c to 3c

In the cases above mentioned you are getting the same service at an increased cost, while on the other hand, the increased amount of service given to the street car rider during the past 10 years, without increasing the unit of fare, has been tremendous It has come in many forms—better cars, faster trips, greater transfer privileges.

Think It Over and Be Fair

The Beaver Valley Traction Company

One-Fifth of All Wealth

OF THE UNITED STATES IS INVESTED IN THE FURNISHING OF TRANSPORTATION, LIGHT, HEAT POWER, WATER GAS AND TELEPHONES.

Twenty-Eight Billion Dollars

Are Represented in This Line of Business

IF THE BALANCE OF THE COUNTRY IS TO BE PROSPEROUS THE TRANSPORTATION LINES MUST BE MADE TO PAY A FAIR EARNING ON THE MONEY INVESTED

Every Other Business Does or Fails

IF THE TRANSPORTATION LINES WERE TO FAIL—IF MONEY SEEKING INVESTMENT IS PLACED IN OTHER LINES OF BUSINESS WHAT ARE YOU GOING TO DO ABOUT TRANSPORTATION?

The Life of a Country Is Its Transportation Facilities

ARE YOU BETTERING OR HINDERING THE PROGRESS OF THE COUNTRY'S LIFE?

THE BEAVER VALLEY TRACTION CO.

All Cars Have Controllers

ALL TEMPERS SHOULD HAVE. IF EITHER ARE MISSING FROM OUR CARS OR EMPLOYEES WON'T YOU GIVE US THE BENEFIT OF YOUR KNOWLEDGE? WE IN TURN PROMISE TO IMPROVE THE CONDITION

The Beaver Valley Traction Co.

4—The results obtained: *First* A public, a large percentage of which is for the first time acquainted with many of our operating problems and costs, and therefore is more appreciative and lenient than they could otherwise possibly be. *Second*—Until the present period of labor unrest, a decreasing number of accidents and their attendant costs. *Third*—On September 16th, 1916, we put into effect without any voiced objections or appeal to the Public Service Commission a new tariff, which abolished books of 100 tickets sold for $4.50, labor tickets and school tickets, which sold at 2.5 cents and 3.5 cents each respectively, in lots that were sufficient for one month's daily use and good only for the month, substituting therefore 21 tickets for $1.00. In January, 1918, after several months of logically cumulative advertising, we abolished the sale of 21 tickets for $1.00, and substituted in their stead, strip tickets in lots of 10 for 55 cents or 6 cents fare if cash fare was tendered.

NO FARE CARS

We have some cars that when needed travel our lines and no fares are received. These are.

THE SALT CARS
THE SNOW PLOW CARS
THE SAND CARS
THE SCRAPPER CARS
THE EMERGENCY CARS
THE WORK CARS

They all represent an investment and must be maintained out of the nickel you pay for your ride

The Beaver Valley Traction Co.

MUTUAL RESPONSIBILITY

Did you ever stop to consider that you as a public are mutually responsible with us for the character of street car service provided here—be it good or bad—as you may have your own opinion in that connection?

Transportation is a commodity It is bought and sold We represent the sellers and you the Public, are the buyers. As buyer and seller there comes a mutual responsibility

Every [illegible] enactment of law that is a detriment to the company is partly a detriment to you. Every [illegible] lengthens the haul or decreases the fare [illegible] expenditure of the income which [illegible] you pay for each ride

Sharing responsibility with us demands that there be [illegible] We offer you that from our side and request [illegible] you

THE BEAVER VALLEY TRACTION CO

We operate through nine towns and two townships. On account of this last raise in fare, the Chamber of Commerce of one community filed a protest upon the last day of grace, for as the directors stated to me, they were there to look after the interests of the community, and although personally none of them was averse to the increase going into affect, merely as a matter of form, to protect themselves if the question should arise in the future, they filed this protest. The Council of the town of course followed suit. Two other towns filed a protest almost three weeks after the new tariff was in effect. Neither of them are pressing the issue. Both the Chamber of Commerce and the Council in by far the largest borough through through which we operate, discussed the matter and decided not to file a protest.

Could this result have been accomplished without the good will of the public? Could the good will of the public have been gained by mediocre service and advertising, or with excellent service, and no advertising. Decidedly not. From the "results obtained" we conclude that continued, truthful, educational advertising does pay.

W. H. BOYCE

Industrial Controllers-XIX

The Production of Coke

H. D. James

EVERY American should be interested in the conservation of our national resources and the making in America of dyes and other chemicals, which were formerly purchased from Germany. For years this country wasted perhaps the most valuable part of the coal in the manufacture of coke. Coke is produced from coal by the action of heat. The process drives off the tar and volatile matter, leaving a hard gray substance known as coke. Until recently the process was carried on in this country in what are known as "bee hive coke ovens". This process produced only coke, and wasted the byproducts.

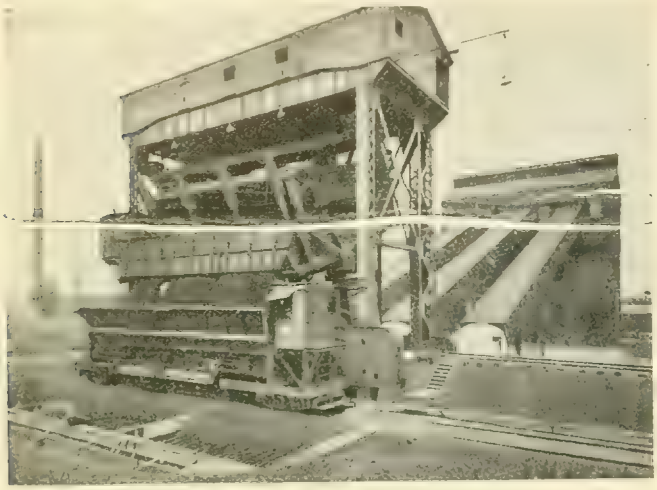


FIG. 1—CAR DUMPER AND COAL HANDLING EQUIPMENT
Of the By-product Coke Plant of the Lehigh Coke Company, South Bethlehem, Pa.

During the past ten years a large number of plants have been built which conserve the byproducts and are often referred to as byproduct coke and gas oven plants. These plants eliminate a great deal of the dust and fumes which originally ruined the country for miles around and, while there is still dust in some of the operations, there is no nuisance or damage to the surrounding country. This dust consists largely of coke breeze which is a very fine coke dust. There is also coal dust in and about the crushers and conveying apparatus. It is therefore necessary to protect all control apparatus from this dust to reduce the maintenance and insure reliable operation. Many of the controller panels are enclosed in cabinets provided with felt packing around the door. Examples of these cabinets are shown in Figs. 2 and 3.

FIG. 2—PUSHER RAM CONTROLLER
Diagram of connections shown in Fig. 5.

The control applications to a byproduct coke plant can best be described by taking up the process of manufacturing coke from the time the coal is received at the plant until the coke is ready for shipment.

FIG. 3—PROTECTIVE PANEL
Doors open and closed. Diagram of connections shown in Fig. 5.

The method of handling the coal from the cars or barges to the receiving bins depends upon the locality and method of receiving the coal. Where the coal is shipped by rail, the car is often elevated to a height of 40 or 50 ft. and emptied directly into the receiving bin. In other cases the coal is emptied into a track hopper and conveyed by belts to the bins. This latter process is shown in Fig. 1. When the coal is received by barges, a regular unloader may be used or some form of hoist with clam shell bucket. Where the coal is

stored in the open, a coal bridge is required. Control for coal and ore bridges has been described in a previous article and the control for car dumpers will be described later.

Coal is conveyed from the receiving bins to the breakers and crushers. These crushers consist of hammer mills or rolls driven by constant speed motors, the controller being of a plain rheostatic type

FIG. 4—INTERLOCKING CONTROL PANELS FOR THE COAL HANDLING MACHINERY
Corresponding to the diagram shown in Fig. 8.

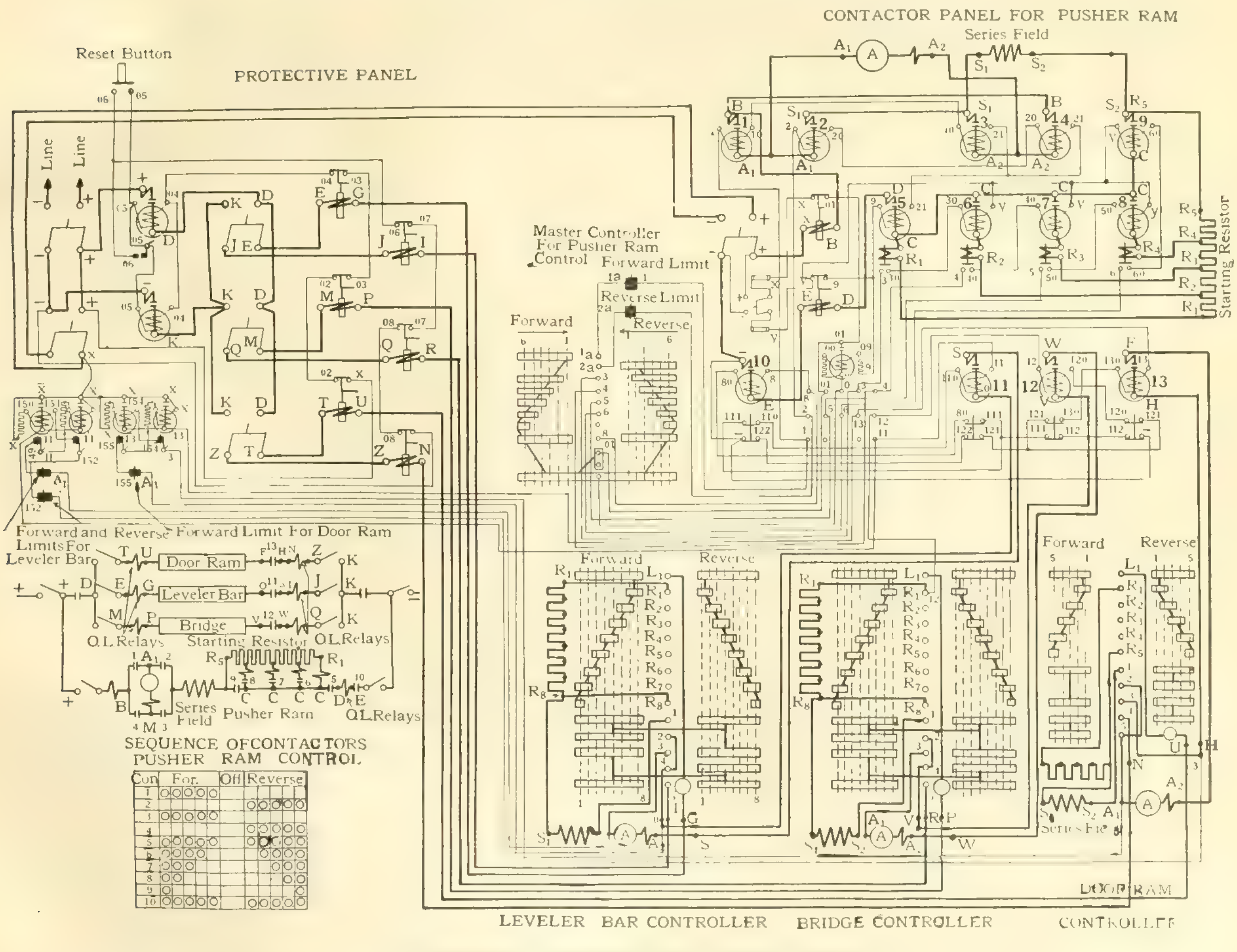


FIG. 5 PUSHER, LEVELER AND DOOR MACHINE CONTROL

The panel at the left is used for disconnecting and protective purposes. It has an overload relay in each side of each motor circuit connected to the drum controllers. The two magnetic contactors are used for opening either side of the line in case any of the overload relays operate. The four small contactors on the lower left hand side of the diagram are used in connection with the limit switches for opening the motor circuits and for interlocking between the controllers. In the upper right hand corner of the diagram is the main control panel for the pusher ram. This consists of four reversing switches, four accelerating switches, one line contactor, and one interlocking contactor. In addition, there are three interlocking contactors one for each drum controller. The four interlocking contactors are so arranged that only one controller can be operated at a time. The magnet contactor control is operated from the six point drum type master switch. The schematic diagram shows the main connections. The sequence table is for the pusher ram control.

for direct-current motors or slip ring motors. Where squirrel-cage motors are used standard autostarters are applied, such as described in previous articles. The starting requirements for these rolls are sometimes quite severe and care should be taken in applying squirrel-cage induction motors to see that sufficient starting torque is available.

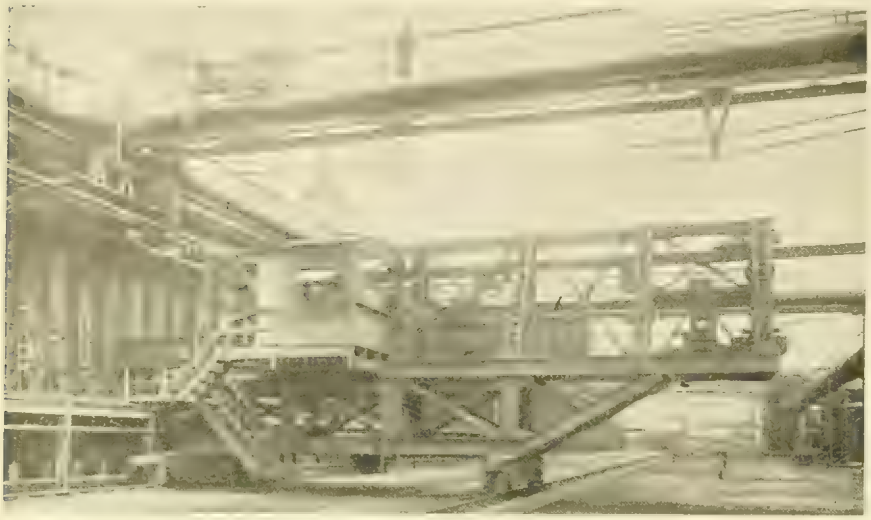


FIG. 6—COMBINED PUSHER, LEVELER AND DOOR MACHINE
Of the Maryland Steel Company at Sparrows Point, Maryland.

The control equipment for coal handling machinery is often combined into one large board located in a dust-proof building. The master controllers, which are usually push buttons, are located close to the individual motors, so that the attendant must be close to the motor when it starts. This arrangement makes it necessary for the operator in charge of starting the motors, to walk the entire length of different conveyors and inspect them together with the driving machinery before starting the motors. Safety stop buttons are located at convenient intervals along the entire length of the conveyor galleries so that the machinery can be stopped if anything goes wrong or an accident should occur. The coal handling control is so interlocked that the machine at the delivery end of the system must be started first and the other machines in their order up to the receiving end of the system. Should a machine in any part of the system stop, all of the machines back of it are automatically stopped to prevent the loading up or accumulation of material in any part of the system. The remaining machinery on the delivery end continues to operate, thus unloading all of the material in that part of the conveyor system. In some plants a relay is used for stopping the conveyor if the load goes off, due to the breakage of a belt, gear, etc. This relay operates to open the contact if the load on the motor falls below a fixed value.

In some instances as many as twenty motors have been interlocked on a system of this kind. As a rule, however, they are divided into two or more groups, each group conveying the material to a storage or mixer bin. Lights or other signal devices are used so that when one group of conveyor motors is started up the operator on the second group is signaled automatically to start up his group.

The ovens are arranged in batteries and are opened at both ends. Each oven is about 18 inches wide by 10 feet high and 40 feet long and has a capacity of from 11 to 16 net tons of pulverized coal. Coal is charged into the ovens by a larry car having four hoppers. This car conveys the coal from the storage above the ovens to the ovens themselves. These cars are generally operated by direct-current motors with the ordinary rheostatic reversing drum controllers. The current is collected and returned to the line from two collector shoes operating on collector bars at the side of the track.

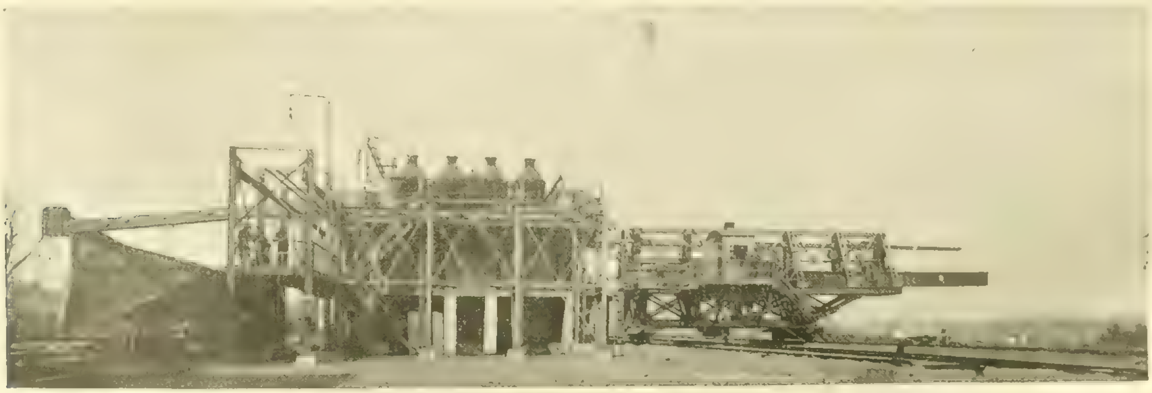


FIG. 7—END OF OVEN BATTERY SHOWING LARRY CAR, QUENCHING CAR AND PUSHER MACHINE
Of the Lehigh Coke Company, South Bethlehem, Pa.

A door machine is provided on each side of the oven. On one side this door machine is combined with a leveling bar and pushing machine, as shown in Fig. 6. On the other side of the oven the door machine is combined with a coke guide through which the coke is forced from the oven into the quenching car. This arrangement is shown in Figs. 7 and 10.

After an oven has been emptied, the doors at each end of the oven are placed in position by the door ma-

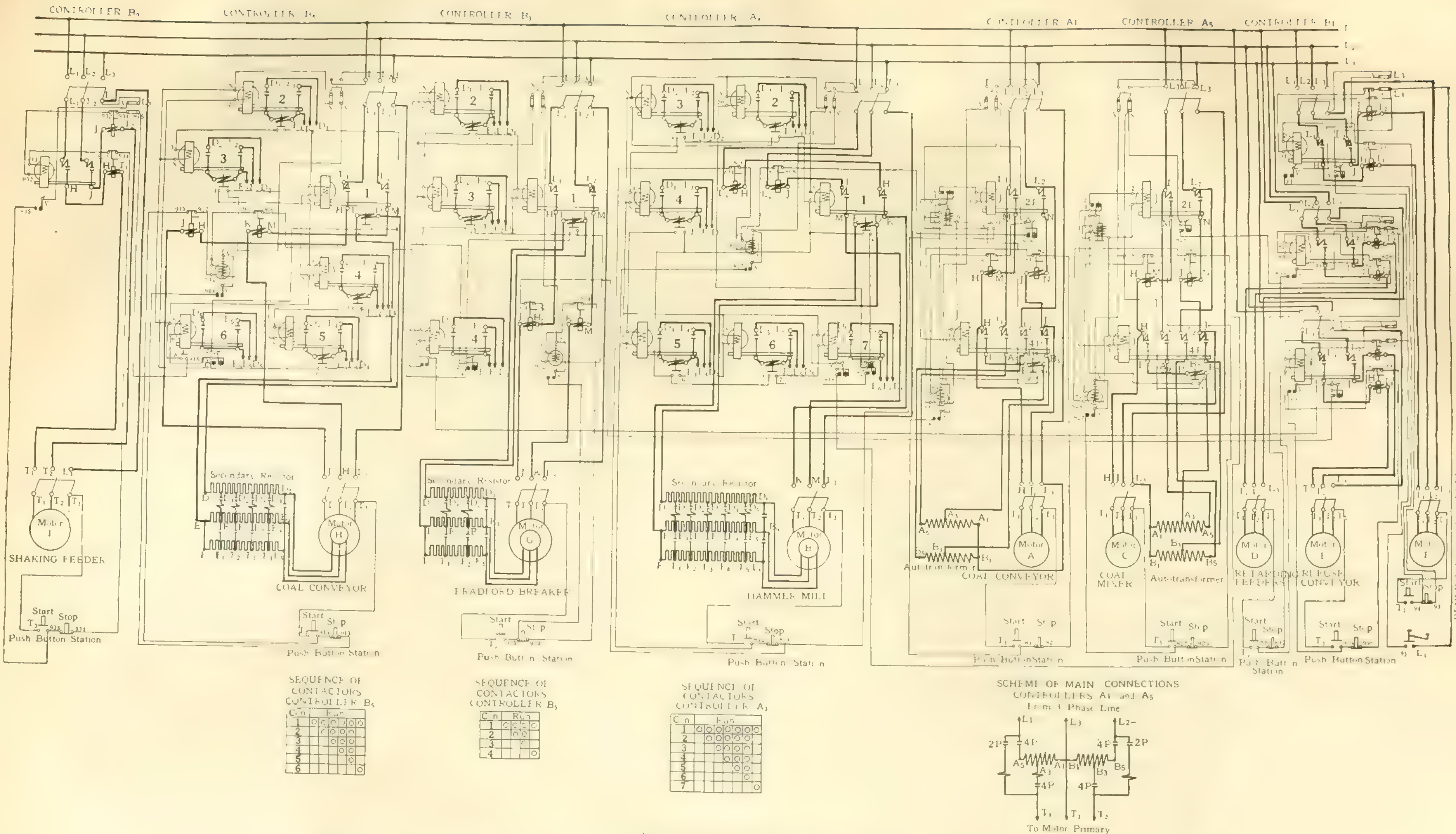


FIG. 8—COAL HANDLING CONTROL

The entire motor and control equipment is alternating current. Part of the motors are squirrel-cage and part of the slip-ring type. Each controller is of the contactor type and self-contained, provided with a push button for starting and another button for stopping. The controllers are interlocked so that motor *A* must be started first, then motors *B*, *C*, etc. If motor *C* is stopped, motors *D, E, F, G, H* and *I* will also stop automatically. It will then be necessary to start motor *C* before the others can be started. The operating of any one of the stop buttons stops all of the motors ahead of that control. This diagram has been simplified by omitting all duplicate equipment. The actual control system provides for additional motors.

chines and then sealed with clay to make them air-tight. A small opening is provided in the top of one of the doors for the leveling bar which levels off the coal dis-

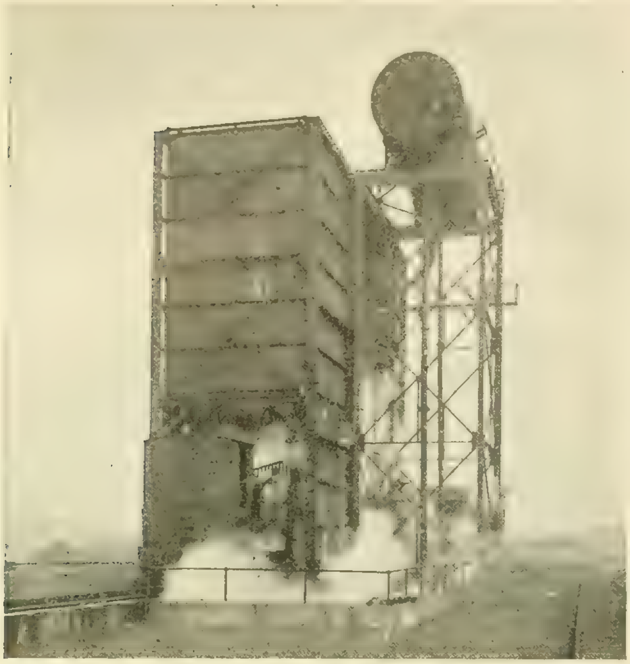


FIG. 9—COKE QUENCHING STATION OF THE LEHIGH COKE COMPANY, SOUTH BETHLEHEM, PA.

charged into the oven by the larry car. After the oven has been completely charged this small opening is closed and sealed. The coking process requires from 14 to 22 hours. When the coke is ready for removal from the oven the door on the one side is removed, the coke guide is placed opposite the opening and the quenching car is placed opposite the coke guide. The pushing bar is inserted from the opposite side and the coke forced out through the chute into the quenching car. This is shown in Figs. 6, 7 and 10.

The control for the combined pusher, leveler, and door machine is shown in Fig. 5. The various operations are often interlocked to insure safety in handling the coke and in the movement of the machine. The controllers are of the usual rheostatic reversing type. Both drum controllers and magnetic contactor panels are used, depending upon the size of the motor and the work to be done. Limit switches are provided to prevent over-travel for the machines which have positive limits of travel. The quenching car is moved by a 20 ton electric locomotive which takes it to the quenching station where water is dicharged on the coke in the car to reduce its temperature so that it can be handled readily. Fig. 9 shows a load of coke being quenched at the quenching station.

The locomotive then conveys the coke to the coke wharf Fig. 10 where the coke is discharged and allowed

FIG. 10—COKE WHARF AND COKE QUENCHING CAR*
Of the Lehigh Coke Company, South Bethlehem, Pa.

conveyors by a rotary feeder and conveyed to a screen which separates the coke from the coke breeze or dust. The electrical apparatus which operates the feeding conveyor and screen is subject to a great deal of coke dust and must be carefully protected. The control apparatus is usually the ordinary rheostatic type; either alternating-current or direct-current motors may be used, the latter being preferable on account of having fewer moving parts.

The gas and fumes which are distilled from the coal during the formation of coke are conveyed to various tanks and stills where the byproducts are separated and refined. The electrical apparatus for this part of the equipment has no unusual features. During the heating process when the coal is changed to coke, in a well known type of oven, the direction of the gas through the ovens and flues is changed about every thirty minutes. This change is usually taken care of by clock-work which operates the motors that change the dampers.

Alternating-current motors are preferable for all conveyors, crushers, damper regulators and screens. These motors have fewer moving parts than a direct-current motor and are less likely to be affected by the dust. Direct-current motors are preferable for traction purposes, also for the pusher, leveler and door machine, and for the unloading machines, either a car dumper or a hoist. All of the motors and controllers in a coke plant are subject to a great deal of dust and fumes. Special treatment should be given the exposed windings and motors and in some cases, artificial ventilation is provided so that clean air can be taken from the outside and passed through the electrical apparatus.

Little or no speed variation is required on a good deal of the apparatus. Where speed regulation is required, direct-current motors are recommended. An important feature in the control equipment is the proper interlocking of groups of controllers to prevent accident.

*Figs. 1, 6, 7, 9 and 10 were furnished through the courtesy

The Engineering Evolution of Electrical Apparatus-XXX

The History of Indicating Meters

Chas. R. Riker

"SCIENCE is measurement" said Sir John Herschel; and the history of electricity bears out his definition. The surpassingly rapid growth of the electrical industry is without doubt due to the fact that electrical and magnetic effects can be measured more accurately than can those of other forms of energy.

The original type of voltage indicating instrument was probably some form of electroscope for indicating the presence of static electricity. Franklin and other early experimenters were familiar with this general type of instrument. From this it was an easy step to some form of electrometer for comparing charges; a

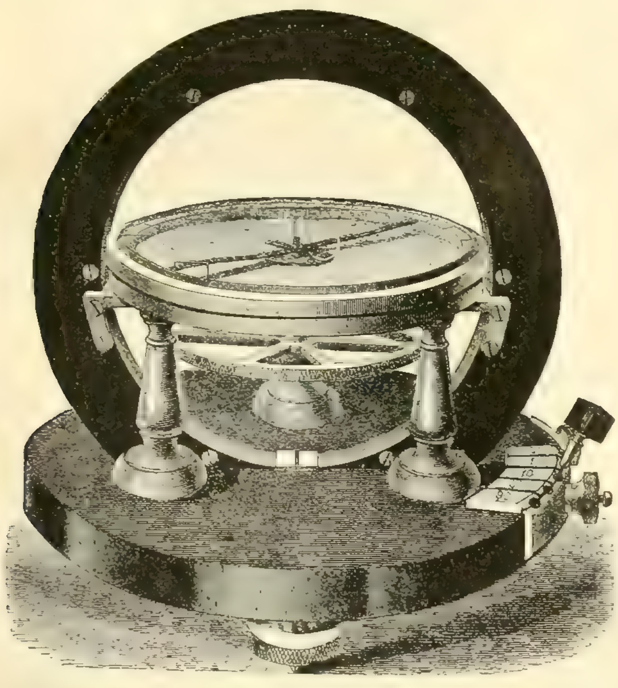


FIG. 1—WESTERN UNION STANDARD TANGENT GALVANOMETER
As exhibited at the International Electrical Exhibition in Philadelphia, 1884.

third and more radical step being the change to that type of instrument which would measure absolute values—in other words, the static voltmeter. This latter step was, however, delayed until after the discoveries of Volta and Faraday paved the way to the use of dynamic electricity.

Similarly the initial current indicating instrument was undoubtedly the magnetic needle with which Oersted in 1820 first demonstrated the effect of a voltaic current in a wire upon the magnetic needle and with which Ampere a few months later demonstrated the direction and magnitude of this effect. From these early experiments it was an easy step to wind several turns of the wire into a coil to increase the effect of the current, leading to the development of the various forms of sine and tangent galvanometers, which were the only current measuring instruments known to early experimenters. A tangent galvanometer, which was exhibited at the International Electrical Exhibition at Philadelphia in 1884 as one of the most improved forms of measurement is shown in Fig. 1. The scale of the galvanometer was marked in degrees, so that a calibration table or curve was necessary. The most accurate method of calibrating the galvanometer at that time was by the use of the silver or copper voltameter, the current being maintained at a constant value for an hour or more and the deposit on an electrode carefully weighed. From this weight the current value for any particular reading of the instrument could be calculated.

The great defect of the tangent galvanometer was its weak field and its susceptibility to stray magnetic fields. The logical development was to produce an instrument having an artificial field sufficiently strong to eliminate the effect of magnetic disturbances and in which a relatively light moving element would produce positive indications. This important step was taken in the instrument shown in Fig. 2 which was described by Deprez and D'Arsonval in 1882. From the standpoint of later developments this was one of the most interesting of the early instruments. It consisted of a moving current carrying coil suspended by a torsion thread under tension between the poles of the permanent magnet. The torque produced by the coil in the strong magnetic field was much greater than in previous instruments and could be opposed by a greater restraining influence.

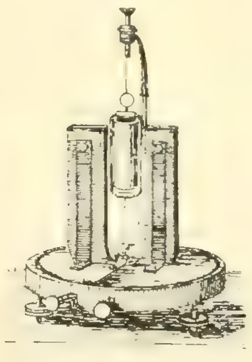


FIG. 2—EARLY D'ARSONVAL GALVANOMETER

By reason of the fact that the fundamental principles upon which most electric meters are based were more or less understood before there was any particular commercial demand for these instruments, the development of many of the more common types has taken place almost coincidently. For the same reason the development of the earliest commercial forms of most of the different types was coincident with the need for such instruments—hence with the development of the central station, and has occurred almost entirely since

1882, although experimental and laboratory forms were in use prior to that date. It is almost impossible therefore, to discuss these instruments in a chronological order and their history will be treated rather by types.

D'ARSONVAL INSTRUMENTS

It was early recognized that the principle involved in the D'Arsonval galvanometers was of value. Ammeters and voltmeters using permanent magnets, and

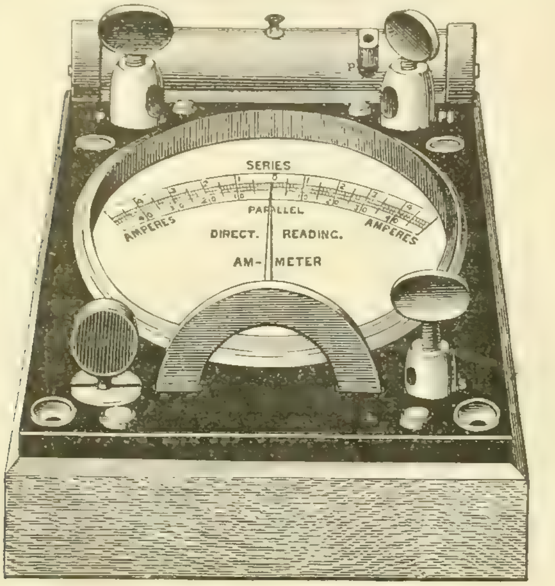


FIG. 4—EARLY WESTON D'ARSONVAL TYPE VOLTMETER

having a moving element restrained by springs and mounted between pivots, were exhibited at the Electrical Exhibition in 1884. Inside of these meters there was a needle of soft iron in the interior of a bobbin formed by several turns of a copper ribbon insulated in layers.

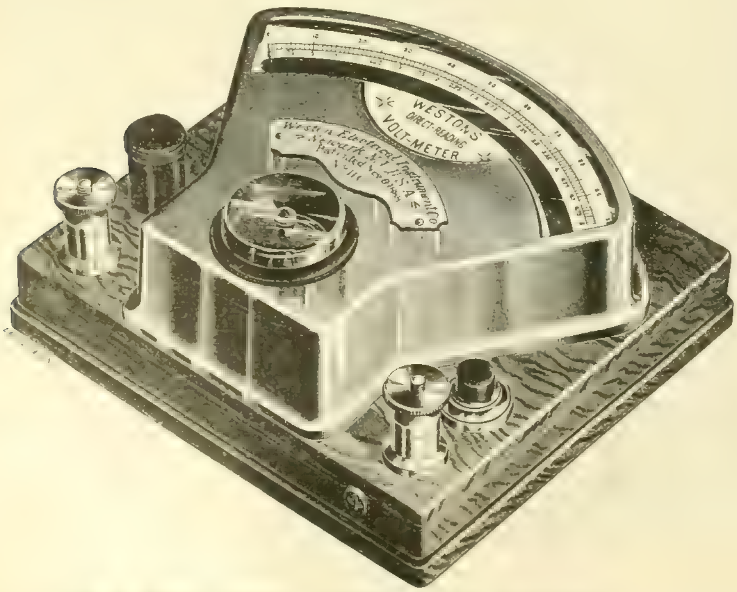


FIG. [illegible]—EARLY WESTON D'ARSONVAL TYPE VOLTMETER

The needle was mounted on an axis and swung between the poles of a permanent c-shaped magnet. The coil was placed obliquely between the two poles. "Reductors" were provided for use with both the ammeter and the voltmeter, consisting of shunts and series resistors.

A transition type of instrument, interesting because of the many auxiliary features of interest it included, was described before the Physical Society (London) in Jan. 1884 by Profs. Ayrton and Perry. This meter, shown in Fig. 3, had a direct reading, uniform, double

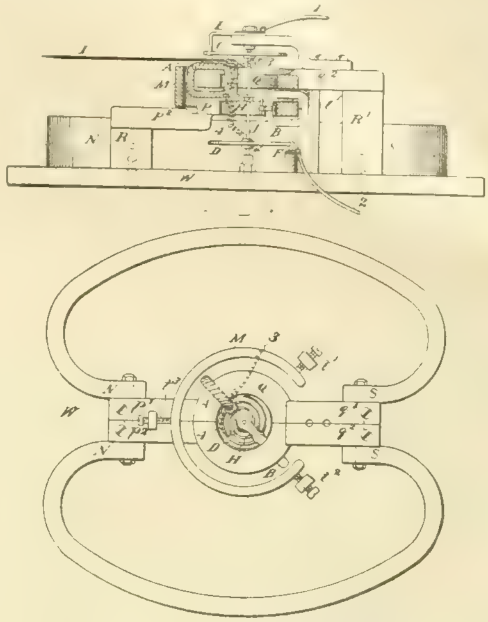


FIG. 5—EARLY D'ARSONVAL STATION VOLTMETER OF THE SINGLE AIR-GAP CONSTRUCTION

scale, corresponding to two ranges of current or voltage, and was dead beat. In spite of its external resemblance to a modern meter, however, this was simply a modified form of sine galvanometer in which the earth's field was replaced by that of the permanent magnets, the polarized needle being swung from its normal position in the controlling field by the action of the deflecting field set up at right angles to the controlling field by the current to be measured. The uniform scale was obtained by careful pro-

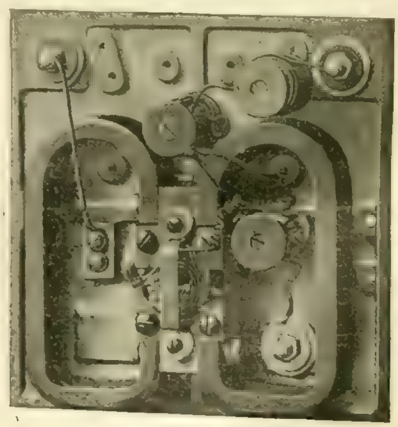


FIG. 6—PORTABLE TYPE SINGLE AIR-GAP WESTINGHOUSE D'ARSONVAL VOLTMETER

portioning of the pole pieces. Calibration and correction for changing strength of the permanent magnets was affected by screwing in or out the soft iron cores inside the deflecting field coils. A 10:1 scale ratio was produced by series-parallel connection of the windings. Ammeters, voltmeters and direct-reading ohmmeters of

this type were manufactured. Although a marked improvement over earlier meters, this type had two serious defects. It was not, especially when new, permanent in its calibration; and a serious heating error was introduced when it was kept in the circuit for even a short time.

Both of these defects were overcome and other improvements were made in the D'Arsonval type of instruments by Mr. Edward A. Weston, who in 1888 patented the type of meter shown in Fig. 4, which for many years was considered as practically the standard direct-current meter in this country. These were among the first instruments built in this country as practically all indicating meters had, up to this time, been imported or manufactured under European licenses. Probably the greatest advance which should be

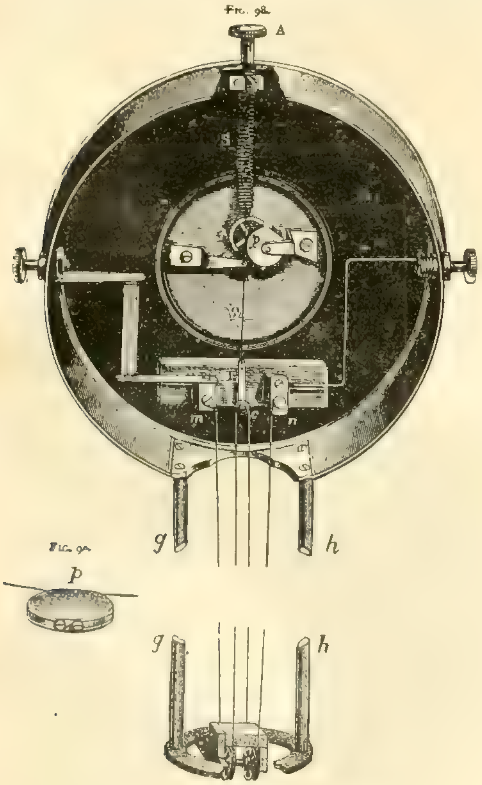


FIG. 7—CARDEW HOT WIRE VOLTMETER

credited to Dr. Weston was careful ageing of permanent magnets before the meters were manufactured, so that their calibration remained constant for long periods of time. Of no less importance was the development of instruments which could be connected permanently in a circuit without having their indications thrown off by the heating of the windings. This was accomplished by making an instrument having exceedingly small losses but nevertheless of extreme sensibility. Both the ammeter and voltmeter were of the same type, each being a very sensitive millivoltmeter which has shunted across a fixed resistance in the case of the ammeter and was placed in series with a high resistance in the case of the voltmeter. Another valuable feature of this instrument was its dead beat characteristic, which was produced by having the moving coil mounted on a soft iron armature between the pole pieces of the permanent magnets, so that eddy currents, induced by the rotation of the armature, promptly damped out any oscilliations. In the initial form of this instrument, the moving coil was completely enclosed in an electro-deposited coating of copper in which the damping currents circulated. This was later replaced by a metallic bobbin on which the coils were wound. The mirror under the needle, to avoid parallax errors, was another valuable feature of these instruments.

A further development of the D'Arsonval principle is that shown diagramatically in Fig. 5 which was patented by Mr. Shallenberger in 1897 with the idea of obtaining a longer range of scale than could be obtained in previous types. The principal improvements comprised in this instrument were its single air-gap and the arrangement of the parts so that the mechanism could be taken apart for inspection or repairs, without changing the magnetic circuit and hence without affecting the calibration. In this meter, the flux in the air-gap was at right angles to the plane of the flux in the permanent magnets, and the pole pieces consisted of two concentric circles, one of which was surrounded by a coil on a very light frame and the other by a damping coil, so

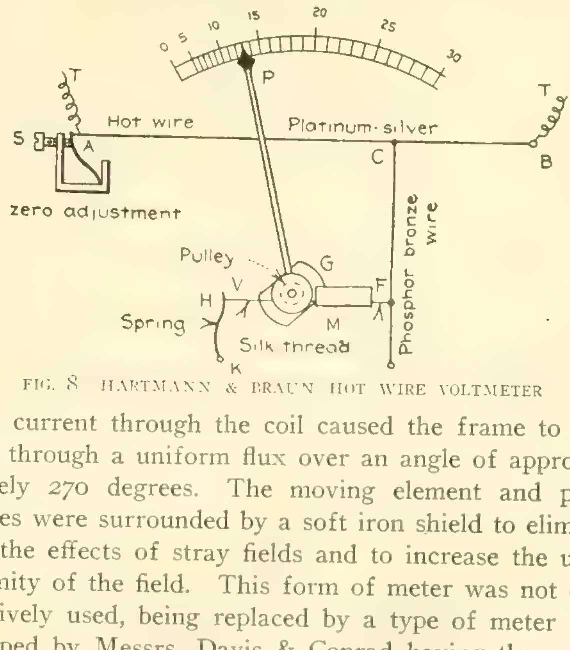


FIG. 8 HARTMANN & BRAUN HOT WIRE VOLTMETER

that current through the coil caused the frame to rotate through a uniform flux over an angle of approximately 270 degrees. The moving element and pole pieces were surrounded by a soft iron shield to eliminate the effects of stray fields and to increase the uniformity of the field. This form of meter was not extensively used, being replaced by a type of meter developed by Messrs. Davis & Conrad having the same general form of air-gap, but with the pole pieces covering only a semi-circle, only a single coil being used which was wound on a damper frame. A still later form of this same general type of meter is shown in Fig. 6. The moving coil is pivoted on one side so that the coil balances the weight of the pointer, and this, by making balance weights unnecessary, results in a very light moving element. The single air-gap can be made larger than where two air-gaps are used and is therefore more easily kept free from iron dust or filings. The entire magnetic circuit can be magnetized and put through the ageing process as a unit.

HOT-WIRE INSTRUMENTS

Among the earliest measuring instruments were those depending upon the thermal effects produced by

an electric current. The earliest commercially successful instrument of this type was developed by Professor Cardew. It consisted of a platinum silver wire which ran twice from end to end of a yard long brass tube passing over insulated rollers at each end as shown in Fig. 7. Both extremities of the wire and the pulleys at

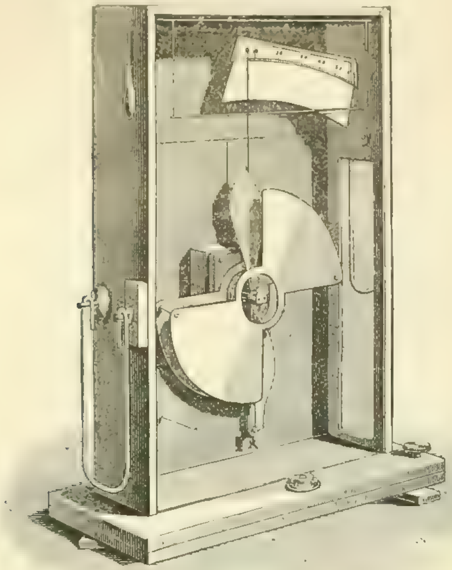


FIG. 9—EARLY ELECTROSTATIC VOLTMETER

the ends of the tube were fixed, the pulley at the center of the wire being free to slide. The wire was kept taut by a spring attached to the sliding pulley by a wire which passed around a drum to which the needle was geared. This gearing greatly amplified the motion due to the expansion of the wire, which was slight. A spiral spring attached to the pointer took up all back lash. The tube was made partly of iron and partly of brass, proportioned so that the coefficient of expansion was equal to that of the wire; hence, so long as both were of the same temperature, the readings were independent of external variations. The objections to this instrument were its cumbersome size, the time required for it to attain a constant reading and its large power

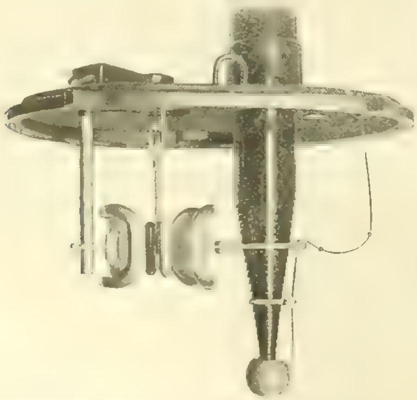


FIG. 10—CON[illegible] [illegible]MINAL TYPE ELECTROSTATIC VOLTMETER

consumption (approximately one-half ampere for a voltmeter). The earlier form of the instrument was provided with a uniform scale in degrees and a calibration table was supplied with the instrument, but in the later forms the scale was direct reading in volts and amperes.

To avoid the long tube of the Cardew type, various modified schemes were used, the most successful being that by Ayrton and Perry and by Hartman and Braun shown in Fig. 8. The needle of the Ayrton & Perry voltmeter was damped by means of a number of fine hairs brushing on the dial. Another type of hot-wire instrument devised by Professor Perry, consisted of a strip of platinum-silver which had been fixed at both ends, heated and twisted in the middle until it acquired a permanent set. The characteristics of such a double twisted strip are that when placed in tension the center rotates. A pointer was placed in the middle and tension permanently applied sufficient to give one complete revolution of the pointer. The current was passed through the strip and as its temperature increased, the strip expanded, releasing the torsion and thereby causing a motion of the needle.

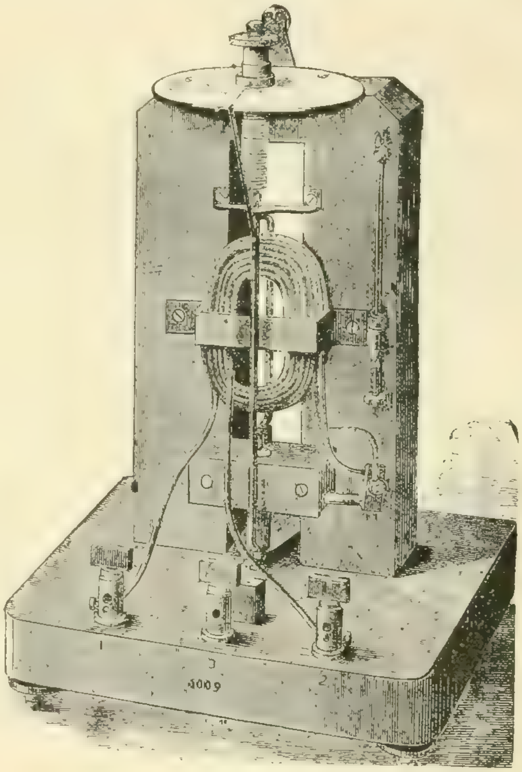


FIG. 11—DYNAMOMETER TYPE AMMETER

Instruments of the hot-wire type are used at present only for the measurement of high frequency currents, such for instance, as occur in wireless telegraphy.

ELECTROSTATIC VOLTMETERS

As previously stated the electrostatic voltmeter was a logical development from the earlier forms of electroscopes. One of the earliest forms was Thomson's (Lord Kelvin's) quadrant electrometer, which was limited to laboratory use by the delicacy of its silk fiber suspension. This form of instrument was commercialized later by several firms. A static voltmeter which was developed by Prof. Thomson before 1885, and which is still on the market in essentially the same form, consisted of two movable plates placed between four stationary plates, as shown in Fig. 9, in such a manner that an attraction between the movable and stationary plates tended to move the former about the axis

upon which they were pivoted. Various other forms of condenser plates have also been used. Owing to the weakness of the attraction between the electrometer plates, the electrostatic voltmeter was suitable only for the higher voltages; and although Thomson developed a voltmeter having a range of 40 to 100 volts by mounting a number of quadrants and vanes above each other, since the development of other accurate and inexpensive means of measuring voltage, the electrostatic voltmeter has been used only for the higher voltages, and for those direct-current circuits in which the entire absence of current is of value. One of the most practical of the more recent instruments was developed by Mr. S. M. Kintner. This instrument could be used with a maximum scale reading of 100 000, 50 000 or 25 000 volts, by keeping two condensers in series with the instrument or by short-circuiting one or both of them. The moving element was immersed in oil which served also as insulation between the stationary elements. The oil permitted much smaller separation than in air and

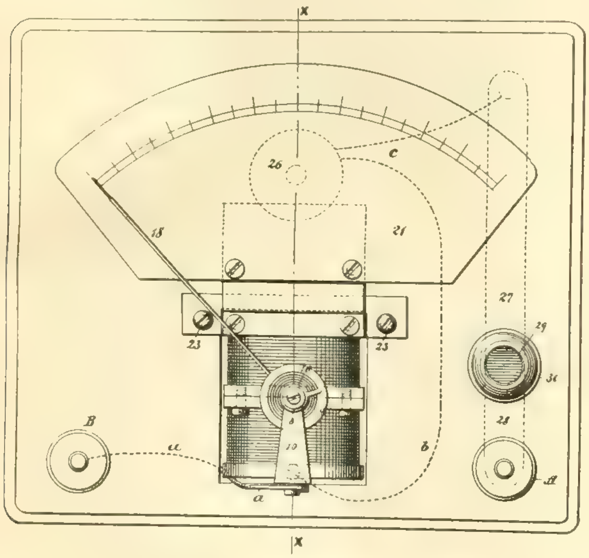


FIG. 12 —WESTON DYNAMOMETER VOLTMETER

hence the actuating forces were increased greatly and the overall dimensions of the instruments considerably decreased. The oil also acted as a damper, making the instrument nearly dead beat, and also buoyed up the moving element, practically removing all weight from the bearings. In a later form of this instrument, introduced in 1910, the condensers were replaced by a section of a condenser-type terminal, as shown in Fig. 10. In this type of instrument, any maximum voltage for which the condenser-type terminal can be built can be measured directly.

ELECTRODYNAMOMETER INSTRUMENTS

The principle of electromagnetic induction which produced the first electrodynamic generators resulted also in the dynamometer type of current measuring instruments, which were introduced into this country by Siemens and Halske Company. These instruments, shown in Fig. 11, are built on the same principle as a direct-current series motor without iron in the magnetic field; that is, the flux set up by the fixed magnet coil caused a movable coil carrying the same current to tend to move, this tendency being restrained by a spring. The movable coil was suspended from a pivot, and the lower ends dipped into cups of mercury which served to convey the current without friction. Attached to the

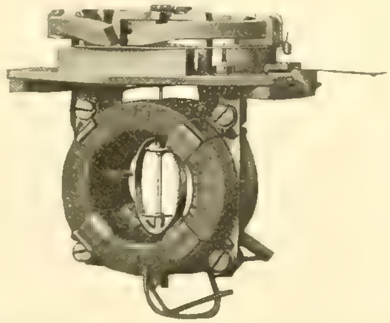


FIG. 13 —WESTINGHOUSE DYNAMOMETER VOLTMETER MOVEMENT

movable coil was a pointer which was kept at zero by twisting a knob attached at the other end of the spring. The position of the indicating needle attached to this knob on the dial served as a measure of the current. The scale was graduated in degrees so that a calibration table or curve was required for each instrument, the same as with the tangent galvanometers, the deflection being proportional to the square of the current. By winding both strips of coils with very fine wire this instrument could be used as a voltmeter; or by winding one coil with fine wire and the other with coarse wire it could be used as a wattmeter.

The same principle of operation was later embodied by the Whitney Company in greatly improved mechanical form and with a direct-reading scale, in the well-known line of Hoyt instruments. In these instruments the moving coil was suspended between pivots and the current was carried to the moving elements through the springs.

Another development of this same principle produced a direct-reading instead of a null scale; that is, instead of adjusting the spring to maintain the moving coil in the stationary position, the coil carrying with it a pointer, until the magnetic torque was balanced with that of the spring. This type of instrument was commercialized in many different forms, among the more

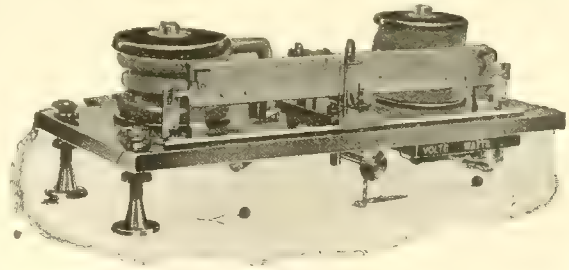


FIG. 14 —KELVIN BALANCE

prominent of which were the Weston voltmeter, and wattmeter shown in Fig. 12, the Thomson inclined coil voltmeters, and wattmeters, and the Westinghouse instruments of the general type shown in Fig. 13. In all instruments of this kind, the scale deflection is proportional to the product of the cur-

rents in the two coils as long as the angle between the coils is small. In a wattmeter this produces an approximately uniform scale, but in a voltmeter or ammeter the needle deflection is normally proportional to the square of the current. If the angle of movement between the coils is appreciable this relation between current and deflection is changed. By suitably locating the coil, or by inclining the coil as in the Thomson instruments, an approximately uniform scale was produced over the effective range. All of these dynamometer type instruments are equally accurate on direct and alternating current, provided there are no stray magnetic fields or provided two readings are taken on direct current with reversed connections to eliminate the effects of stray fields.

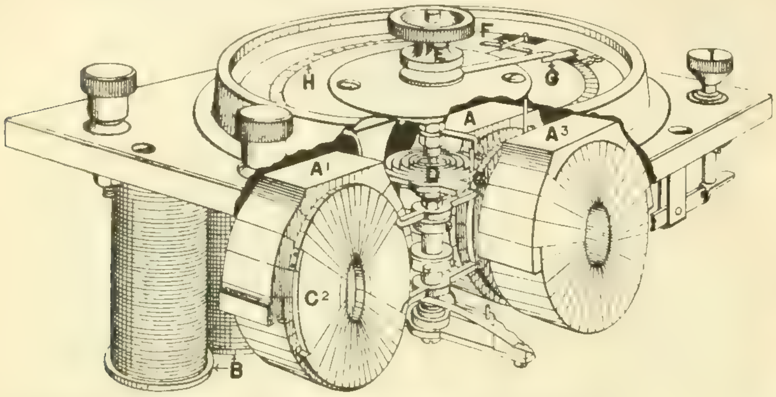


FIG. 15—ZERO READING KELVIN BALANCE TYPE OF PORTABLE AMMETER, VOLTMETER OR WATTMETER

FIG. 16—DIAL PLATE OF WESTINGHOUSE PRECISION AMMETER, VOLTMETER OR WATTMETER

Current Balance—One of the most accurate of the earlier dynamometer instruments was the Kelvin current balance shown in Fig. 14. This has a movable coil located between two stationary coils on each end of a balance pivoted at the middle, the relation of current flow in the various coils being such that the movable coil is attracted by the lower stationary coil and repelled by the upper stationary coil on one side of the balance and repelled by the lower coil and attracted by the upper stationary coil on the other side. Weights are added to one side of the moving element, a balance arm and rider being provided for finer adjustments. The weight required to balance the moving element was proportional to the square of the current.

A more recent application of the same principle is shown in Fig. 15 which shows a null-reading instrument operated in the same way as the early dynamometers and Hoyt instruments, but securing much greater accuracy by having the coils arranged the same way as in the Kelvin current balance. For convenience in mounting, the coils are arranged in a vertical plane and their action is restrained by a spring. This type of instrument gives a long range of scale readings as shown in Fig. 16, and is provided with a vernier for increased accuracy. *(To be Continued)*

The Essentials of Transformer Practice-XII

Yearly Cost of Operation

E. G. Reed

IN THE following analysis certain assumptions have been made regarding the cost of power, cost of transformers and conditions of load, which may not conform exactly to the conditions for any particular case. Such costs are subject to considerable variation from time to time and the values used in the examples given, are the ones prevailing when this article was written.

COST OF ELECTRICAL ENERGY

The cost of making electrical energy is usually thought of as being made up of two main elements:—

1—Production cost.
2—Fixed charge.

The items making up the total production cost are those which vary with the amount of energy produced, such as fuel, lubricants, water, etc. The items making up the total fixed charge are those which are practically independent of the total energy produced, such as the investment and administration charges. The investment charge is made up of interest, taxes, insurance and depreciation on the power station and distributing system of sufficient capacity to supply the maximum demand of the total connected load.

The investment charge equals the rate of annual charge times the total cost of the equipment. The rate of annual charge is usually made up as follows:

5.0 percent for interest.
1.5 percent for taxes.
1.5 percent for insurance.
3.0 percent for amortization.
Or a total of 11 percent.

The administration cost is for the salaries of officials and for office expenses in general.

The production cost is usually specified in cents per kilowatt-hour. It is more convenient to use this cost in dollars per watt year in the following calculations. To reduce cents per kw-hr. to dollars per watt year, multiply by $(24 \times 365) \div 10^5$ or 0.0876.

EFFECT OF LOAD FACTOR ON PRODUCTION COST AND FIXED CHARGE

A typical daily load curve for a distributing transformer is shown in Fig. 1, from which it is evident that the load factor is far from 100 percent. The production cost varies slightly, and the fixed charge to a considerable extent, with the load factor. A low load factor involves the use of a relatively large amount of equipment operating at light and inefficient loads. With a high load factor all the elements that enter into the

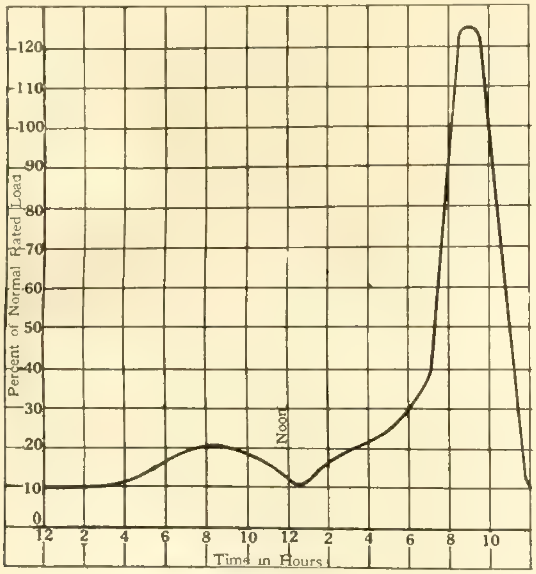


FIG. 1—TYPICAL DAILY LOAD CURVE ON A FIVE K.V.A. TRANSFORMER

This load curve corresponds to the generally accepted understanding that the performance characteristics of distributing transformers should be based on a load condition of four hours at full load and twenty hours at no load. This gives a loss factor (mean square ordinate) of $4 \div 24 = 0.167$. Load factor of this curve $= 0.24$.

production of power are operating at maximum economy, and the cost of power is a minimum. An exact definition of the 24 hour load factor for a period of one hour's maximum load is the ratio of the actual net output during that period to the product of the maximum hour output by the total numbers of hours in the period. Thus the daily load factor on this basis, is,—

$$\text{Load Factor} = \frac{\text{Actual net output for day of 24 hours}}{\text{Net maximum hour's load} \times 24}$$

Or, expressed in another way, the load factor is the average daily use of the maximum demand, expressed as a percentage of 24 hours. The maximum demand is the maximum power taken, and may be based upon an instantaneous peak or cover a specified time.

Production cost has been found to vary approximately as the fourth root of the load factor.* Or the production cost at a given load factor is,—

$p\left(\frac{1}{\text{Load Factor}}\right)^{\frac{1}{4}}$, where p is the production cost at unity load factor.

Example 1—If the production cost from Table I for a 5000 kw plant is 0.347 cents per kw-hr. for 100 percent load factor, what is the production cost for a 24 percent load factor as shown by the curve in Fig. 1?

$$\text{Production cost} = 0.347\left(\frac{1}{0.24}\right)^{\frac{1}{4}} = 0.5 \text{ cents per kw-hr.}$$

Since the load factor is the ratio of the average daily hours output to the maximum hours demand, a low load factor will require a large system to supply the maximum demand. For example, a system which delivers a certain amount of energy during a 24 hour period with a 25 percent load factor, must be something less than four times the size of another system which supplies the same total energy in the same period with a 100 percent load factor. In the latter case the system will be less than four times the size in the former case, because with a low load factor the maximum demand exists only for a short time, for which the natural overload capacity of the system may be utilized. Assuming that the overload capacity of a

TABLE I—COST OF POWER GENERATION
In cents per kilowatt-hour at 100 percent load factor.*

Size of Station Kilowatts	Fuel	Labor	Oil Waste and Supplies	Repairs and Maintenance	Total Production Cost	Fixed Charges	Total
500	0.449	0.132	0.026	0.025	0.632	0.148	0.780
1000	0.364	0.094	0.019	0.021	0.498	0.124	0.622
2000	0.328	0.073	0.015	0.018	0.434	0.107	0.541
3000	0.304	0.065	0.013	0.016	0.398	0.095	0.493
4000	0.289	0.058	0.011	0.014	0.372	0.086	0.458
5000	0.271	0.053	0.010	0.013	0.347	0.080	0.428

station for short periods is 25 percent, the normal capacity with a 25 percent load factor may be taken as $\frac{1}{0.25} \times \frac{1}{1.25}$ or 3.2 times the capacity of the system which operates with a 100 percent load factor. In the following examples it is assumed that the fixed charge varies as the cost of the station which in turn depends on the load factor as indicated above.

Example 2—If the fixed charge is 0.08 cents per kw-hr. for a 100 percent load factor, what is the proper fixed charge for a 24 percent load factor?

$$\text{Fixed charge} = 0.08 \times \frac{1}{0.24} \times \frac{1}{1.25} = 0.27 \text{ cents per kw-hr.}$$

This assumes that the cost of the larger system is the same per kw output as for the smaller one, and that the administration charge varies in the same way as the investment charge. Neither of these assumptions is strictly correct.

YEARLY COST OF TRANSFORMER LOSSES

The total yearly cost of the losses for a transformer, operated on the daily load curve shown in Fig. 1, will be,—

*See "Standardization of Methods for Determining and Comparing Power Costs in Steam Plants," by Messrs. H. G. Stott and W. S. Gorsuch, *Proc. A. I. E. E.*, Vol. XXXII, p. 1099.

*From "Typical Electric Power Costs" by Mr. M. C. McNeil in the JOURNAL for March 1914, p. 135.

$$\text{Dollars per year} = p(L_i + F\,L_c) + d(L_i + L_c) \;\ldots\ldots (1)$$

Where p is the production charge in dollars per watt year, d the total fixed charge including the investment and administration charges, expressed in dollars per year per watt of peak demand, L_i the iron loss of the transformer in watts, L_c is the copper loss at normal rating and F is the quantity which, multiplied by the copper loss at normal load, gives the actual continuous loss over the daily load curve. Therefore F is the mean square of the load curve when the ordinates of the load curve are expressed as percentages of normal load. The first term of equation (1) gives the total charge per year against the transformer on account of the actual energy consumed by the losses. The second term gives the annual charge on account of the extra equipment which must be provided to supply the energy during the peak load period. The cost of the transformer losses is figured in this way because the total cost of power for the entire station output must be the sum of the costs of the individual items making up the total load. For convenience equation (1) may be written,—

$$\text{Dollars per year} = L_i\,(p+d) + L_c\,(pF+d) \;\ldots\ldots\ldots (2)$$

Example 3—What is the yearly cost of supplying the losses of a 5 k.v.a. transformer, on the daily load curve shown in Fig. 1, when $L_i = 42$ and $L_c = 100$.

This copper loss of 100 watts is based on a wattmeter measurement at 75 degrees C. in line with the A. I. E. E. rules. The average temperature of a distributing transformer, with a normal full-load temperature rise of 55 degrees C. operating on the load curve shown in Fig. 1, will doubtless be something less than 75 degrees C. and the assumption made is therefore subject to some slight criticism for this reason. With a load factor of 24 percent,

Production cost from Example 1 = 0.5 *cents per kw-hr.*
Fixed charge from Example 2 = 0.27 *cents per kw-hr.*

Since these figures are based upon costs at the central station, it will be assumed that the costs of electrical energy delivered to the distributing transformer is approximately 25 percent greater. Then,

Production cost = 0.5 × 1.25 = 0.625 *cents per kw-hr.*
Fixed charge = 0.27 × 1.25 = 0.338 *cents per kw-hr.*

When expressed in dollars per watt-year these figures become,—

Production cost = 0.625 × 0.0876 = \$0.055 *per watt-year.*
Fixed charge = 0.338 × 0.0876 = \$0.0297 *per watt-year.*

Therefore,—

$$p = 0.055$$
$$d = 0.030$$
$$p+d = 0.085$$
$$pF+d = 0.039$$

Then from equation (2),—

Dollars per year = 42 × 0.085 + 100 × 0.039 = 3.57 + 3.9 = \$7.47.

Of the total cost of \$7.47 per year, \$3.57 is for the iron loss and \$3.90 is for the copper loss.

COST OF TRANSFORMER EXCITING CURRENT

The transformer exciting current causes a copper loss in the generating and primary distributing system, which is continuous as long as the transformer is connected to the line. Since it is continuous and a true energy loss, this copper loss must be placed in the same class as transformer iron loss. The loss varies with the magnitude and power-factor of the load; the greater the load and the lower the power-factor, the greater will be the copper loss.

The exciting current is composed of two parts, one which magnetizes the iron circuit and another which supplies the actual iron loss. Since the magnetic flux in the iron circuit of the transformer is a maximum when the impressed voltage is zero, and zero when the impressed voltage is a maximum, the impressed voltage and magnetic flux are 90 degrees apart in time phase relation. The magnetizing element of the exciting current, being in phase with the flux, is also at right angles to the impressed voltage and is therefore wattless. On the other hand the eddy and hysteresis loss represents actual energy loss, which appears as heat in the magnetic circuit. The current which supplies this loss is in phase with the impressed voltage and is a working current. The total current on the primary side of the transformer from Fig. 2, is,—

$$I = \left[I^2_L + m^2 I^2_L - 2\,m\,I^2_L \cos\{180^\circ - (\beta - \theta)\} \right]^{\frac{1}{2}}$$

Where I_L is the primary load current due to the load current on the secondary side, and mI_L is the exciting current. In this case m is the ratio of the exciting current of the transformer to its normal full-load current. The total line loss is equal to the square of the current multiplied by the total resistance on the

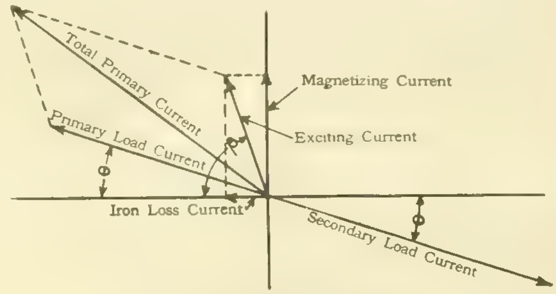


FIG. 2—VECTOR DIAGRAM

Showing that the total current in the primary winding of a transformer is made up of the vector sum of the iron loss current, the magnetizing current and the load current.

primary side of the transformer, including that of the generator, distributing lines and other intervening apparatus, such as step-up or step-down transformers. The total distributing loss is therefore,—

$$L_d = I^2_L\,R + m^2\,I^2_L\,R + 2\,m\,I^2_L\,R\,\cos\,(\beta-\theta)$$

Where R is the total resistance on the primary side of the transformer as described above. If the transformer is operated only F percentage of the 24 hours at normal full-load, the total distributing loss becomes,—

$$I^2_L\,RF + I^2_L\,RF\,m\left[m + 2\cos\,(\beta-\theta)\right]$$

The part of this loss due to the normal primary working current I_L is $I^2_L\,RF$ and the part due to the exciting current is $m\,I^2_L R\,F\,[m + 2\cos\,(\beta - \theta).]$ Expressing $I^2_L R$ in terms of the power delivered in watts, it may be written,—

$$I^2_L\,R = 1000\,cP$$

Where c is the ratio of the distributing copper loss to the total k.v.a. delivered and P is the k.v.a. rating of the transformer. The copper loss in watts due to the exciting current is then,—

$$L_d = 1000\,mcPF\left[m + 2\cos\,(\beta-\theta)\right]$$

The total output P may represent the output of any number of transformers or of a single unit. Express-

ing this in terms of the iron loss of the transformer as 100 percent gives,—

$$Percent\ L_d = \frac{1000\, mcPF\left[m + 2\cos(\beta-\theta)\right]}{L_1} \ldots\ldots\ldots\ldots (3)$$

The angle $(\beta-\theta)$ is determined as follows from Fig. 2, the primary voltage of the transformer being E,—

$$\cos\beta = \frac{\frac{L_1}{E}}{mI_1} = \frac{L_1}{1000\, mP} \ldots\ldots\ldots\ldots (4)$$

and the angle θ is the one whose cosine is equal to the power-factor of the load. The data in Table II will be found useful in numerical calculations.

Example 4—Let the following data refer to a group of transformers operating on a basis of four hours at full normal load and 20 hours at no-load.

For the exciting current .... $m = 0.018$
For the distributing copper loss .... $c = 0.12$
Iron loss .... $L_1 = 42$
Power-factor of load .... $= 0.9$

Therefore since cos θ is 0.9, $\theta = 25$ degrees, 51 minutes.

From equation (4),—

$$\cos\beta = \frac{42}{1000 \times 0.018 \times 5} = 0.467$$

Therefore $\beta = 62$ degrees, 11 minutes.
Then $\cos(\beta - \theta) = 0.805$

From equation (3) the percent distributing loss now becomes,—

$$\frac{1000 \times 0.018 \times 0.12 \times 5 \times 0.167\ (0.018 + 2 \times 0.805)}{42} = 0.070$$

That is, the loss in the system due to the transformer exciting current is equal to practically seven percent of the iron loss of the transformers, or a yearly cost of $3.57 × 0.07 = $0.25.

TABLE II—VALUES OF COS $(\beta-\theta)$

β (degrees)	Cos β	Cos $(\beta-\theta)$ For 100% P-F	For 90% P-F.	For 80% P-F.	For 70% P-F.	For 60% P-F.
78	0.208	0.208	0.616	0.755	0.848	0.906
75	0.259	0.259	0.656	0.788	0.875	0.927
72	0.309	0.309	0.695	0.819	0.899	0.945
69	0.358	0.358	0.731	0.848	0.920	0.961
66	0.407	0.407	0.766	0.875	0.940	0.974
63	0.454	0.454	0.799	0.899	0.956	0.985
60	0.500	0.500	0.829	0.920	0.970	0.992
53	0.602	0.602	0.891	0.961	0.992	1.000

It is interesting to compare the cost of the exciting current as given in Example 4, which is four hours at full load and 20 hours at no-load, to the cost for continuous operation at full load. The latter cost is given in the following example, with all other conditions the same as for Example No. 4,—

Example 5—From equation (3) the loss is,—

$$\frac{1000 \times 0.018 \times 5 \times 0.12 \times (0.018 + 2 \times 0.805)}{42} = 0.42$$

This gives a yearly cost of the exciting current of $3.57 × 0.42 = $1.50.

COST OF TRANSFORMER REGULATION

The current consumed by the load on a transformer is proportional to the voltage delivered. Therefore, since the power consumed by the load is proportional to the product of the voltage and the current, it is proportional to the square of the impressed voltage. If R be the regulation of the transformer, the percent of normal voltage delivered at full-load will be,—

$$Percent\ of\ voltage = \left(\frac{E - \frac{RE}{100}}{E}\right) = 1 - \frac{R}{100}$$

The percentage of power delivered is therefore,— $\left(1 - \frac{R}{100}\right)^2$ and the actual power in watts is,—

$$Actual\ power\ delivered = \left(\frac{100 - R}{100}\right)^2 1000\ PF$$

Where P is the k.v.a. rating of the transformer, and F is the quantity which, multiplied by the normal rating of the transformer, will give the actual energy delivered during a given daily load curve. The case of 90 percent power-factor is assumed as being that of the average distributing circuit. The energy not sold due to the regulation of the transformer is,—

$$= 1000\ PF - \left(\frac{100 - R}{100}\right)^2 1000\ PF$$

$$= \left[\frac{2R}{100} - \left(\frac{R}{100}\right)^2\right] 1000\ PF$$

Multiplying by the profit per year realized in selling energy, gives the yearly loss,—

$$Dollars\ loss\ per\ year = \left[\frac{2R}{100} - \left(\frac{R}{100}\right)^2\right] 1000\ PF \times k$$

Where k = *Profit in dollars per watt year.*

Since the value of $\left(\frac{R}{100}\right)^2$ is small compared to $\frac{2R}{100}$, this relation may be written,—

$$Dollars\ loss\ per\ year = 20\ RPFk \ldots\ldots\ldots\ldots (5)$$

Example 6—What is the yearly loss with a 5 k.v.a. transformer which has a regulation at 90 percent power-factor and full load of 2.67 percent, if the daily load curve is such that the loss factor is 0.167?

Assume that the profit realized from selling a watt-year of energy is approximately 50 percent of the cost of energy delivered to the transformer or say $0.04 per watt-year, then from equation (5),—

$$Dollars\ loss\ per\ year = 20 \times 2.67 \times 5 \times 0.167 \times 0.04 = \$1.76$$

A part of this loss might be eliminated by the use of regulating devices tending to keep the voltage constant at the secondary terminals of the transformer. However, it is customary to take care of drop in primary voltage only by the use of a potential regulator.

TOTAL COST OF OPERATING A TRANSFORMER

The total cost of operating a transformer includes not only the cost of supplying its losses and a charge for its exciting current and regulation, but also the annual charge on the money invested in the transformer. The total cost of operating the transformer therefore consists of the following items,—

1—Investment charge.
2—Cost of iron loss.
3—Cost of copper loss.
4—Cost of exciting current.
5—Cost of regulation.

Example 7—What is the total cost of operating a 5 k.v.a. transformer whose cost is $51, with a rate of annual charge of 11 percent, all other conditions being the same as for the preceding examples?

1—Investment charge	$ 5.61
2—Cost of iron loss from Example 3	3.57
3—Cost of copper loss from Example 3	3.90
4—Cost of exciting current from Example 4	0.25
5—Cost of regulation from Example 6	1.76
Total	$15.09

Example 8—What is the total yearly cost of operating a 5 k.v.a. transformer, whose cost is $43.50 and whose performance characteristics are as follows,—

$L_1 = 58$ $L_c = 110$.
$m = 0.063$ Regulation at 90 percent power-factor = 2.85.

1—Investment charge	$ 4.78
2—Cost of iron loss	4.93
3—Cost of copper loss	4.30
4—Cost of exciting current	0.66
5—Cost of regulation	1.90
Total	$16.57

It is evident that, under the assumed conditions, the transformer in Example 7 is the most economical one to use. The difference in the yearly cost being \$16.57—\$15.09 or \$1.48, the cost of the transformer in Example 7 could be increased from \$51.00 to \$64.50, without its total yearly cost of operation exceeding that of the transformer in Example 8.

Example 9—Would it be economical to replace an old 5 k.v.a. transformer, which has the following performance characteristics, by the 5 k.v.a. transformer in Example 7,—

$L_1 = 75$ $L_2 = 120$
$m = 0.063$ Regulation at 90 percent power-factor = 3.03.

The additional investment is the cost of the new transformer, which is \$51 plus say 10 percent of this value for making the change, minus about 20 percent for the scrap value of the old transformer, or a net amount of \$45.90.

Therefore,—

The yearly cost of the new investment	\$ 5.05
Total yearly cost of the losses and regulation of the old transformer	13.78
Total yearly cost of the losses and regulation of the new transformer	9.48

The yearly saving on the losses and regulation by the use of the new transformer would be \$13.78—\$9.48 or \$4.30. Since this is less than the cost of the additional investment of \$5.05, it would not be advisable in this case for reasons of economy only, based on the assumed conditions, to scrap the old transformer and replace it with the new one.

*The author is indebted to Mr. J. B. Gibbs, for assistance in the preparation of this section.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1609—TRANSFORMERS WITH UNBALANCED LOAD—Will a modern pole type, oil cooled, five k.v.a., 60 cycle, single-phase, 2200 volt primary, 220 and 110 volt, three wire secondary transformer handle a load that has 35 percent more amperes on one side than the other and keep the voltage even on both sides of the circuit? We have now a 10 k.v.a. transformer handling 23 k.v.a. connected load and the voltage on one side is 90, on the other side 130 (this is not satisfactory) on a Saturday night peak load, but when there is no peak the high voltage changes sides. I am thinking of putting in to replace this a modern transformer of five k.v.a. to handle 11.3 k.v.a. connected load and transfer the other 11.7 k.v.a. which is wired on the two-wire system to a two-wire distribution system that is within reach, but the changes still leave an unbalanced load of 35 percent which cannot be changed without tearing the building to pieces. The load on the new transformer will be 19 amperes on one side and 27 on the other. The voltage on the outside wires is 220. What will be the voltage on the center to each outside wire respectively? Will this modern transformer carry the voltage evenly or would it be better to buy a balance coil? E.B. (ALTA.)

A transformer designed for three-wire service will carry an unbalanced load up to 50 percent of its rating, providing the k.v.a. output of the heavily loaded side is not greater than one-half the k.v.a. rating of the transformer. The percent voltage drop of this side will not be greater than the regulation of the transformer which is about 2.5 percent. With a load as described, the k.v.a. output of the side with 27 amperes load will be 110 x 27 = 2.97 k.v.a. or an overload of 19 percent on a five k.v.a. transformer. It is assumed that the transformer is well designed being a shell type, or if it is a core type, the low-voltage is subdivided, *i.e.*, part of each of the low-voltage coils on each side. A five k.v.a. transformer of good design will carry this load without difficulty. The voltage will be about 107 volts across the heavily loaded side and about 108 volts across the other side. This will give a voltage of 215 volts across the outside wires with a high voltage of 2200 volts. As the unbalanced load is less than one-half k.v.a. it is not advisable to install a balance coil. C.B.

1610—ALUMINUM CONDUCTORS IN DYNAMOS—I understand that in spite of the war Switzerland is continuing the manufacturing of electrical apparatus using aluminum or zinc conductors in the machinery in place of copper. It would seem that motors built of aluminum would be of larger size but should be lighter and possibly cheaper. What would be the effect of using aluminum or zinc conductors upon the operating characteristics of direct-current and alternating-current motors and generators? L.G.B. (PA.)

There are very few cases where aluminum can be used to advantage as current conductors in dynamo-electric machinery. The reason that aluminum and zinc is used so much for this purpose in some parts of Europe, is that copper is nearly unobtainable there. Where the use of aluminum requires a longer magnetic circuit on account of its greater bulk for the same current-carrying capacity, the weight and size of the machine as a whole is very likely to be increased. This applies particularly to revolving fields, revolving armatures and transformers, and is also true of most stationary fields and armatures. The cost of the machine will, therefore, be increased usually, even though the cost of aluminum be somewhat less than copper for the same carrying capacity. In this country, almost the only purpose for which aluminum could be used to advantage in electric machinery, would be for field coils of some direct-current generators, which have sufficient space for such field coils. In addition to its greater bulk, aluminum has some other disadvantages: thoroughly satisfactory electrical joints are difficult to make; the use of the oxide coating as insulation between turns is only a partial success; its mechanical properties are not so good as those of copper; and, unless cotton-covered, cannot be wound "mush", as is often done with copper. The effect upon performance of the use of zinc or aluminum is mainly a loss in efficiency. The increased size means greater ability to dissipate heat, and therefore greater losses are permissible for the same temperature rise. F.L.M.

1611—POWER-FACTOR METER—In taking our meter readings we find that our calculated power-factor runs considerable higher than our power-factor instrument reading with a very nearly balanced load. Our apparatus is three phase, using a three-phase wattmeter and power-factor meter. Method of calculation would be,—

$$\frac{\text{wattmeter reading}}{\text{E.M.F.} \times \text{C} \times 1.732} = \text{Power-factor,}$$

which is considerably higher than power-factor meter reading. Our power-factor meter reading is usually quite low around 60 to 78 varying between these two points. What is the usual percent error in a case of this kind and what instruments used in this case are most subject to error? E.M. (N.Y.)

The formula stated should give the correct power-factor with balanced load and voltage, and there would seem to be no reason why a power-factor meter should read lower than the calculated power-factor, unless some of the instruments are out of calibration or not properly connected. The standard power-factor meter will, under balanced load conditions on a sine wave, indicate the true power-factor within two degrees. It is, however, more subject to error than the instruments used in taking readings for calculating the power-

factor. The power-factor meter indicates the average angle between currents and voltages in a polyphase circuit, the scale usually being lettered so that the reading appears in terms of cosine of the angle rather than the angle. The true power-factor, however, is the ratio between real and apparent watts obtained from ammeter, voltmeter and wattmeter readings. This true power-factor equals the cosine of the angle between the current and voltage only with balanced load and true sinusoidal waves. With distorted waves or with badly unbalanced load, the power-factor meter reading will be higher than the true power-factor. This does not explain, of course, a power-factor reading which is lower than the true power-factor and, as stated above, our only suggestion is that some of the instruments must be incorrect. If the load had been balanced, which you say is not the case, a correctly connected and calibrated power-factor meter would not register low with certain combinations of unbalanced currents. The whole question of power-factor of polyphase circuits is difficult to discuss as, in the first place, there is no "cast-iron" definition of what power-factor really is on a three-phase circuit. E.A.H.

1612—Winding Design—(a) How is the "winding pitch" or "throw" of the coils determined for alternating-current motors? Why is it 1 and 8, 1 and 13, 1 and 12, 1 and 11, etc., in different motors of same size, type, number of slots, etc. (b) If one had a blank induction motor frame with the nameplate detached, how would he determine the size of conductor and number of turns per coil and how would he determine the proper throw for different pole arrangement? (c) I have noted a few instances where 440 volt induction motors were reconnected for 2200 volts. I don't understand what connection could be used to achieve these results without subjecting the winding to a dangerous voltage strain. Can you explain how this would be done on a 50 hp, 440 volt, squirrel-cage induction motor having 8 poles of 4 coils per pole—96 coils and a throw of 1-13 connected one circuit delta? Would not the higher voltage overwork the iron back of the slots to a dangerous degree?
E.R.W. (UTAH)

(a) The full pitch equals the number of slots ÷ the number of poles. In the motor described under (c) this equals 96 ÷ 8 = 12, giving a throw of 1-13. Chorded windings, having a fractional pitch are described in an article on "Reconnecting Induction Motors," by A. M. Dudley, in the Journal for Feb. 1916. (b) This can hardly be done except by an experienced designer as it practically involves a complete design of a new winding. In general, such a design would involve the following formula:—

$$\textit{Flux per pole} = \frac{45 \times 10^8 \times E}{\textit{Cycles} \times \textit{Cond.} \times \textit{Dist. Factor} \times \textit{Chord Factor}} \qquad (1)$$

in which E = volts per leg, Fig. (a), and distribution factor and chord factor are constants depending upon the phase and type of winding as explained in the Feb. 1916 article. Since the frame is already constructed, the flux is approximately fixed and for modern motor iron may be assumed as roughly equal to 80 000 lines per square inch cross section. For a three-phase, 60 cycle motor, the distribution factor may be assumed as 0.95 and the chord factor roughly as 0.96. The frequency and voltage are of course known, as is the desired speed. Assuming 220 volts and 60 cycles and substituting known values in equation (1) gives

$$80000 \times \textit{sq. in.} = \frac{45 \times 10^8}{60 \times \textit{Cond.}} \times \frac{220}{0.95 \times 0.96} \qquad (2)$$

The square inches to be figured should be twice the area of the cross section X-Y-Z-W, Fig. (b), of the core, since the flux divides and goes both ways. The section of the teeth at the middle point should also be checked. It will be the cross section of one tooth × the total number of teeth ÷ by the total number of poles for which the machine is wound. This will give the cross sectional area per pole at the middle of the teeth and if applied in eq. (2), should be multiplied by 0.636 since the maximum value of the flux should be figured in the teeth. This automatically takes care of itself in the core without the factor 0.636, but this factor has to come in the teeth thereby decreasing the flux per pole that can be allowed.

Eq. (2) contains only one unknown, the number of active conductors per phase. Solving eq. (2) gives the number of series conductors per phase. The number of conductors per coil can be calculated, as the total number of coils is fixed by the number of slots. The size of the individual conductors is also determined by the slots in the core

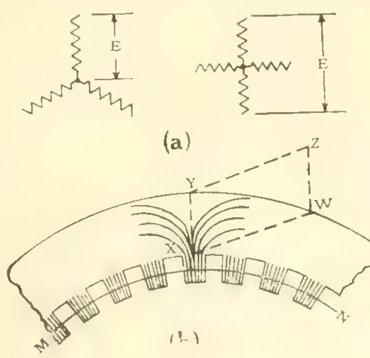


FIG. 1612 (a) and (b)

which is already constructed, as naturally the largest size of conductor which will go into the slots with the required number of turns and with adequate insulation is the size which would be selected. It is entirely possible that a full pitch winding cannot be used under the circumstances, and if a chorded winding is used the chord factor given above will have to be changed. This is all discussed in the Feb. 1916 article. The horse-power rating of the rewound motor can be determined by making arbitrary assumptions as to the current capacity, power-factor, efficiency, etc. In general, a roughly conservative value can be determined by assuming 750 circular mils per ampere in the armature winding, an efficiency of 0.88 and power-factor of 0.80, although this will of course be only a very rough approximation. (c) It might be possible to reconnect a 440 volt motor for 2200 volts so far as the diagram only is concerned. The higher voltage would not overwork the iron if the number of turns in series were increased as much as the voltage, that is 2200 ÷ 440 or 5 times. The 440 volt insulation would not be sufficient for 2200 volts and the coils would have to be entirely reinsulated, which would probably require the use of a smaller size conductor. A.M.D.

1613—Grounding Resister—We are interested in the method of grounding a system through a resistance as outlined in an article by Mr. H. M. Collbohm in the Journal for Jan. '18. We are considering this method in connection with our 11 000 volt, 3 phase, isolated delta system and would like to obtain more details, such as the approximate cost and size of the resistance; the limiting current you would recommend for a system consisting of a double circuit wood pole transmission line 13.2 miles long with approximately 13.6 miles of distribution line. The main generating station has two 3750 k.v.a. and one 6350 k.v.a., 12 000 volt star connected generators (hydroelectric). The power is transmitted from here 13.2 miles to a hydroelectric generating station of one 1500 k.v.a., 12 000 volt generator and a steam plant (only occasionally used) which will shortly have a 7500 k.v.a. turbine generator. Which generator would be preferable for connecting in the resistance? Any other information pertaining to this method you may send us, will be appreciated.
J.S.B. (GA.)

The following recommendation is based on the assumption that present loads are balanced and that a value of 75 amperes unbalanced current would be distinguishable on the feeder instruments. In case there is a greater unbalance in current that would render such an indication unreliable, it will be necessary to increase the value to a point that will give a definite reading. A resistance having a rating of 75 amperes designed for a neutral voltage of 6900 volts and with a time rating of two minutes would require approximately 30 cu. ft. space for installation. This space does not include the clearances other than the supporting insulators for the voltage class of equipment. It is immaterial what generator neutral is used for this resistor, but we would suggest the use of a neutral bus arranged so that one machine would be available at all times. F.C.H.

1614—Transformers Connections—We have had trouble with two banks of transformers connected delta delta as shown in Fig. (a) and both banks connected in parallel. Say transformer marked X of No. 1 bank burns out. On this transformer being disconnected and No. 1 bank now connected open delta, would it be quite alright to again operate this bank in parallel with No. 2 bank? If so, what proportion of the total load will this bank carry? R.H.N.L. (BRIT. COL.)

In effect this condition amounts to having a delta in which two legs, of two parallel transformers each, are used with a third leg which is a single transformer as shown in Fig. (b). This gives double the impedance in the third leg that there is in each of the other two. Knowing the resistance and reactance of each transformer it is possible to calculate the currents in each by the method described in the Electric Journal for Sept. 17, p. 356, in the article on "Dissimilar Transformers in Delta." For example, if the resistance is 1.2 percent and the reactance 2.4 percent it will be found that the current in the single leg will be 0.433 of the cur-

rent in the line. If the three legs of the delta were similar this value would be $\frac{1}{\sqrt{3}}$ or 0.577. Therefore, the load on the bank may be $\frac{0.577}{0.433}$ = 1.33 percent of the load on a bank of three of the same transformers. That is, three 100 k.v.a. transformers of the above characteristics would give a combined output

FIG. 1614 (a) and (b)

of 300 k.v.a. An additional transformer in each of two legs will increase the output to 300 x 1.33 = 400 k.v.a.; while a sixth transformer added to the single leg will make the output 600 k.v.a. See also article on "Operation of Delta and V-Connected Transformers in Parallel," by Mr. E. C. Stone in the JOURNAL for April 1910, p. 304. J.B.G.

1615—PHASING HIGH-TENSION LINES—In the article on "Phasing Out High Tension Lines," by Mr. E. C. Stone in the November 1917 issue, he states in the latter part of the second paragraph as follows: "If both lines have an odd number of delta and an odd number of star windings they can be paralleled with each other, but not with a line having no transformers." Will you please explain why this is true? B.J.S. (OHIO)

It will be obvious from a study of the diagrams in this article that a star delta or delta star connection introduces a 30 degree phase displacement. It will be equally obvious that a second delta star or star delta connection will restore the original phase relation. A delta delta connection or a star star connection does not affect the phase relations. If both lines have an even number of star and even number of delta connected windings the equivalent resultant will be the same as if all the connections were either delta delta or star star; hence there will be no resultant change in phase relations and the two lines can be paralleled with each other or with a line having no transformations. If, however, both lines have an odd number of delta and an odd number of star windings, any attempt to resolve them into the equivalent number of delta delta and star star connections will leave one star and one delta; the effect is the same as if there was one star delta connection in the lines. This will twist the phase relations of the terminals 30 degrees out of phase from the generators. Since both lines will have an equivalent phase displacement they can be paralleled with one another. But since both are 30 degrees out of phase with the generators they cannot be paralleled with a line having no transformations; nor with a line having an even number of star and delta connections. C.R.R.

1616—CIRCUIT BREAKING HEATING—In a G-1, 35 000 volt, 300 ampere, oil circuit breaker, is any heat generated in the iron tank? Does it vary with the current passing through the switch? Would the heat generated be enough to make any noticeable difference in the temperature of the oil when exposed to cold? C.A.A. (MINN.)

Currents of 300 amperes or less will cause no appreciable heating in a structure of the size of the G-1 circuit breaker, especially with the comparatively large radiating surface of the tank. The oil will not be warmed by this current, and to prevent freezing when exposed to cold, a special grade of oil should be used or else heating elements placed in the oil tanks. Oil can be obtained having a low freezing point (— 47 degrees C). Heating elements operated from low voltage can be installed which, for this size circuit breaker will require somewhat less than one kw continuously to raise the oil to 32 degrees F. from 0 degree F. The heaters need be in circuit only during periods of low temperature. H.E. MacD.

1617—LOCKING OF INDUCTION MOTORS—I have been much interested in reading 1550 on the "Locking of Induction Motors." (a) Will you please explain why motors with two-phase rotors, (assuming of course, the same stator and supply), do not give such good starting torque and general performance as motors with three-phase rotors? How is the leakage reactance of motors with three-phase stators and two-phase rotors calculated? (b) The answer to 1550 states that "To prevent locking the number of stator and rotor teeth and their size must be so proportioned that the reluctance of the air-gap will be as nearly as possible the same all around and for all positions of the rotor." Please tell me how to do this. If possible, give a formula for calculating the reluctance of the air-gap which takes all the necessary factors into account. (c) Am I correct in assuming from this answer that a rotor with totally enclosed slots with the slots considerably below the periphery of the rotor, so that the bridge at the top of the slots is not saturated, will cause the reluctance of the gap to be uniform? (d) I have frequently tested motors, chiefly those having two-phase rotors, which appear to give a greater starting torque (with the correct resistance in the rotor circuit) than pullout torque. How can this be explained? F.A.A. (ENGLAND)

(a) The reactance of the motor with a two-phase rotor will be slightly greater than with a three-phase rotor, and hence, the starting and pull-out torques will be slightly less. The reactance of the two-phase rotor is first figured as two-phase and converted to the primary three-phase by mutiplying one-half the ohms between terminals by the square of the voltage ratio. This gives the reactance per leg three-phase or one-half the reactance between terminals. (b) There is no formula for this and each individual case must be laid out step by step. (c) In the case mentioned the reluctance of the air-gap will not be uniform unless the primary teeth are closed also, but there is no position of the rotor in which the effective length of the air-gap is different from any other position of the rotor. Assume the case with open slots and the same number on both members. When the teeth are in line a certain m.m.f. will produce a certain flux. If the tooth is opposite a slot, the path for the flux through the air is greater and the same m.m.f. will produce less flux. (d) These apparent results will seem to occur on account of not being able to read the maximum torque accurately and also at start there may be some eddy current losses which will add to the starting torque. C.W.K.

1618—COPPER STRAP WITH ROUND CORNERS—Knowing the width and breadth of a strap of copper, having round corners, as it is commercially used in the construction of transformers, how would you calculate for its exact sectional area? What allowance is made for the area lost by the round corners? R.S.H. (MEXICO)

The corners of rectangular copper strap for use in transformers are rounded in accordance with the following schedule: When thickness is $\frac{1}{16}$ inch and less, radius = T ÷ 2. When thickness is more than $\frac{1}{16}$ inch and less than 0.17 inch, radius = 1-32 inch. When thickness is 0.17 and less than 0.23, radius = $\frac{3}{64}$ inch. When thickness is 0.23 and over, radius = $\frac{1}{16}$ inch. The amount to be deducted from the rectangular area to find the actual area of the copper is $4r^2$ minus $\pi r^2 = 0.8584\ r^2$. Thus for example, the area of a strap 0.129 by 0.250 is 0.129 × 0.250 = 0.03225; 0.8584 × $(1\text{-}32)^2$ = 0.000838; and the area of the copper = 0.031412 sq. in. F.G.

1619—SECONDARY CURRENTS—Is there any fixed relation between primary and secondary currents in slip-ring induction motor? Please give a formula which takes into account primary voltage and speed,—one sufficiently accurate for calculating the size of secondary leads. H.W.B. (MON.)

The relation between the primary and secondary currents in any particular induction motor is fixed, but for a line of machines there is no fixed relation of currents. The secondary current depends on the secondary voltage and this does not bear any fixed relation to the primary voltage in different ratings. When an induction motor is standing still with the secondary leads open, it is just like a transformer and can be designed to have any ratio whatever. The ratio is determined largely by the number of slots and the winding which can be put in them to the best advantage, and is also determined by parts which have been developed for other ratings. The secondary volts and amperes are usually stamped on the nameplate, but if the nameplate is lost, the secondary voltage can be found by measuring the voltage across the open secondary leads when full voltage is applied to the primary. By using the following formula the secondary current can be found when the secondary voltage is given. The full load slip is usually around five percent.

$$I_2 = \frac{hp \times 746}{\sqrt{3} \times E_2 \times (1 - \%\ s_1)}$$

where I_2 = secondary current per lead; hp = horse-power output; E_2 = open circuit secondary voltage between collector rings; $\%\ s_1$ = percent slip from synchronous speed = $\frac{syn.\ speed - speed}{syn.\ speed}$

Since torque is equal to

$$\frac{hp \times 5250}{(1 - \%\ s_1) \times syn.\ speed}$$

$$I_2 = \frac{Torque \times syn.\ speed}{3 \times E_2 \times 7.04}$$

This shows that the secondary current varies with the torque and is independent of the speed at which the motor operates. The above formula is approximately correct for torques up to 1.5 times full-load torque. For higher torques than this the current will increase faster than the torque, due to changing secondary power-factor.

C. W. K.

NEW BOOKS

"The New Knowledge—Robert Kennedy Duncan. 263 pages, 54 illustrations. Published by A. S. Barnes Co., New York City. For Sale by The Electric Journal. Price $2.00.

It is unfortunately true that most engineers, while keeping pace with the rapid progress of events in their own particular field, find it difficult to keep informed with respect to the modern developments in the fundamental subject of physics, upon which all engineering is based. This it not to the discredit of the laymen in the field of pure physics (in which class most engineers and most teachers must be considered), in that it is usually not due to lack of interest on his part. Rather, in these days of the disintegration of the "indivisible" atom and of scientific alchemy, he finds it exceedingly difficult to keep track of all the newer discoveries and theories, dealing with ions, electrons, corpuscles, radium with its various rays and emanations, and other, to him, mystifying terms. For, while all the new discoveries are duly chronicled, these papers are usually difficult of access, are couched in technical language and are frequently dependent upon other papers, (printed elsewhere) for a part of their meaning. To obtain a clear, concise, perspective view of the whole field requires therefore an amount of time and effort which only a few can spare.

The great majority of the laity are therefore greatly indebted to Prof. Duncan, who, in "The New Knowledge" has presented in a clear and readable manner, what he terms "a synthesis of this new knowledge." We recommend this book most highly to those who are not satisfied with the half baked and often false descriptions of the recent discoveries and theories which are given in the popular and too frequently in some of the technical magazines. The extent of this work is well indicated by the Table of Contents, which follows:—

Part 1—Current conceptions:—The Three Entities; Compounds and Elements, Molecules and Atoms.

Part 2—The Periodic Law:—The Mystery of Matter; The Atoms of the Elements; The Table of the Law; The Testing of the Law; The Significance of the Law.

Part 3—Gaseous Ions:—Gases from the Standpoint of Physics; How They Conduct Electricity; Discovery of Ions; A New Kind of Particles; Discovery of Corpuscles; Factors of a Corpuscle; An Experiment; The Speed of a Corpuscle and How it is Estimated; The Relation of the Charge on a Corpuscle to its Mass; How Important it is; How the Electrical Charge on a Corpuscle is Estimated; A New Use for Clouds; How the Mass of a Corpuscle is Determined; Discovery of the One Thing; Properties of Corpuscles; Cathode Rays; Positive Ions; The Other Kind of Particles

Part 4—Natural Radio-activity:—A New Property of Matter—Antecedent Discovery; Discovery of Radio-activity; Discovery of Radio-active Elements; Radium; Becquerel Rays from Radium; The Alpha-, Beta-, and Gamma Rays; Emanations; Emanation X and the Birth of Helium; Thorium, Uranium, Polonium and Actinium; Radio-activity Everywhere.

"Electric Traction"—A. T. Dover. 667 pages, 519 illustrations and 5 plates. Published by Whittaker and Company, New York City. Price $5.00.

This book by an English author, lecturer on electric traction at the Battersea Polytechnic, London, is intended for engineers and advanced students. Generating substations and transmission lines are not considered. The subject matter in general is arranged as follows:—Mechanics of train movement, motors, control, auxiliary apparatus, rolling stock, study of train movement, track and overhead construction, distributing systems and substations. Naturally, most of the illustrations and examples refer to foreign practice. A table of electric locomotives, both foreign and American, is included. A chapter is given on the testing of traction motors, both alternating and direct current. Considerable space is also devoted to single-phase railway motors.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country. The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

JULY 1918

Railway Motor Carbon Brushes

It is difficult to select a grade of carbon brush for railway motors by a casual inspection or any simple tests. To secure the right brushes requires a thorough knowledge of the various grades of carbons, backed-up by long experience in service, and even with this information, wrong applications are sometimes made. When making a selection the following few fundamentals, in connection with operating conditions, should be considered:—

1—Commutation.
2—Life of commutators.
3—Life of brushes.
4—Frequency of inspection.
5—Current density.
6—Cost per car mile.

The above factors will vary more or less with the design of the motor, the design of the brushholder, the correct spacing of the brushes, the condition of the road-bed, the condition of the equipment, the condition of the armature bearing, the condition of the commutator surface, the brush tension, the weight of the car, the number of motors per car, the scheduled speed and the service conditions, etc.

Since all of these factors must be taken into consideration, the best and most reliable results are obtained by making tests of recommended grades in service under actual operating conditions. Carbon manufacturers generally are willing to assist the operator in making service tests. The following general information regarding carbons will help the operating man more intelligently to select carbons for service tests.

MAIN CLASSIFICATION OF BRUSHES

Carbon is a non-metallic element found in both crystaline (made of crystals) and amorphous (non-crystaline—of irregular shape) form. Natural graphite is carbon in a crystaline form, and is mined in many localities. Amorphous or non-crystaline carbon may be obtained in the form of coke or lamp-black. Artificial graphite is obtained by heating amorphous or non-crystaline carbon, such as coke, in an electric furnace to change its structure to a crystaline state.

By the use of the above materials, the following general classes of brushes are made:—

1—Carbon brushes—made of crushed coke and binder
2—Graphatized brushes—made of carbon and then electro-graphitized.
3—Graphite brushes—natural graphite and binder.
4—Metal graphite brushes—natural graphite with metal powder and binder.

With the modern commutating-pole railway motor having commutators undercut, and considering costs per car mile, brush end wear, side wear, breakage, life, commutation, life and maintenance of commutator, etc., these classes of brushes are best suited for railway motor service as follows:—

1—Graphitized brushes—best all-around results.
2—Carbon brushes—next best all-around results.
3—Graphite brushes—very special and limited uses
4—Metal graphite brushes—not used at all.

METHOD OF MANUFACTURE

In the process of manufacture the most important operations, depending upon the class of brush being manufactured, are as follows:—

1—Crushing, carbonizing (if it is done) and cooling.
2—Milling, mixing, cooling and re milling.
3—Moulding and packing in the furnace
4—Gas baking
5—Electric baking or graphitizing.

The two most common general methods of manufacture are:—

Extruded or Squirted—where the material in the form of pulp is forced through a metal die under pressure and then cut off to the desired length and baked with a high temperature to carbonize the bond and permanently set the material. This method is used in making the cheaper grades of carbons, which do not have the strength to resist breaking and chipping in service.

Moulded and Machined—where the material is moulded into blocks under heavy pressure and baked. The carbons are cut from these blocks and machined to exact size. This method is used in making the high grade carbons and gives a brush of uniform texture and strength that is best suited for railway work.

CHARACTERISTICS

In the manufacture of various grades of carbon brushes best suited to meet the requirements of operating conditions, the following characteristics of the brush must be considered:—

Contact drop	Coefficient of friction	Heat conducting
Hardness	Apparent density	Conductivity
Resistance	Abrasiveness	Toughness

DIMENSIONS

Length—For use in the more modern brushholders, the carbon should be not over 2 inches long, that is when new, they should not extend above the top of the carbon box for the following reasons:—

1—If longer, they are subjected to a greater side pressure, due to the action of the contact tip, which increases the side wear, tends to bind the carbon in the box and reduces the direct pressure on the surface of the commutator.
2—If longer, they are discarded due to excessive side wear, before the added length can be used up in end wear.
3—Approximately the same mileage can be secured from the shorter carbon; and hence, since the carbons are bought on a cu. in. basis, the first cost is less.

The Width is not so particular; they can have as much as $\frac{1}{16}$ inch clearance in the box without causing any trouble in service.

Thickness is very important, as the initial clearance between carbon and carbon box should be approximately from 0.006 to 0.008 inch. If it is much less, the carbon will tend to stick in the box and bind, and if greater, it will soon rattle in the box, wearing away the side; it will also tend to chip and break, thus reducing the life of the carbon.

COPPER PLATING

When pig tails were used on brushes, it was considered necessary to copper-plate the carbon to provide a good electrical contact for the shunt connection. With the present design of brushholder having a heavy braided copper shunt from contact tip to carbon box, shunted carbons have been discontinued, so the copper plating is unnecessary; in fact, it is objectionable on the higher grades of carbons as it tends to peal off in service and bind the carbon in the box.

PIG-TAILS OR SHUNTS

For railway work, pig-tails or shunts on carbons have been practically done away with on account of the following reasons:

1—First cost—they were used with the cheaper grades of carbons that had a comparatively short life, which required renewal of carbons at frequent intervals.
2—Inspection—the pit-men could not be depended upon to maintain shunts during inspection.
3—Not very reliable—the design was such that shunts became loose, disconnected, and were not reliable.

With these conditions greatly improved by the use of a higher grade of carbons with longer life, requiring less frequent inspection and by improved methods of fastening pig-tails to carbons, some advantages can be obtained by the use of pig-tails; and in certain specific cases, especially for very heavy current densities they have been adopted with a saving in maintenance. Foreign practice tends to the more extensive use of shunts than is customary in this country.

THE ELECTRIC JOURNAL

VOL. XV AUGUST, 1918 NO. 8

The Skip-Stop System

Five or six years ago, in an effort to improve the service on their lines, several railway companies hit upon the plan of reducing the number of stopping points to about eight per mile, instead of 12 or 15, as determined by the street corners, so that a higher schedule speed might be maintained. If a car capable of running at 25 miles per hour, is required to make four stops per mile, its schedule speed is then reduced to approximately 13 m.p.h. If it is required to make six stops per mile the speed falls to 11 m.p.h., while if it makes nine stops per mile, the speed is cut to nine m.p.h. This matter of having to make about nine stops per mile instead of only four is the fundamental difference between the street car lines in the average city and the elevated or subway lines of certain large centers which, on account of the few stops, are able to give really rapid transit. Unfortunately, however, most of the railways failed to present their cases to the public authorities in a sufficiently clear way to secure the necessary permission to inaugurate any material change.

The serious coal shortage with which the country was confronted last winter and the necessity for conserving the supply of fuel during the remainder of the war has now called attention to another item which also varies with the number of stops. On the average city railway, it is necessary, to burn about 8.5 pounds of coal per car-mile. If the cars make only six stops per mile, the coal required should then be reduced to only 7.25 pounds per car-mile, in spite of the higher speed which is made, and if the stops can be cut to four, only six pounds of coal will be necessary.

In view of this condition, the elimination of unnecessary stops on the electric railways of the country has taken on a new significance. Instead of being a matter advocated by the railway companies for their benefit, the "skip-stop system," is now being requested by the United States Fuel Administration as a war measure for the benefit of the nation. Looked at from this standpoint, the various public bodies having authority in the different cities are gladly granting permission for the adoption of the system. Already, sufficient cities have adopted or have decided to adopt the system to effect a saving of over 400 000 tons of coal annually and it is expected that the system will be put into effect on a nation-wide basis in a way that will increase the yearly saving to over a million tons.

Ordinarily, in adopting conservation measures to help in winning the war, sacrifices of a more or less serious nature are necessary. In the case of the skip-stop system, however, the saving is effected, not by impairing the service of the railway companies, but by actually improving it. It is to be hoped, therefore, that while the Fuel Administration is asking for the adoption of the measure for the period of the war only, it will be found desirable to retain it as a permanent method of bettering the transportation systems.

CLARENCE RENSHAW

Economy in Trolley Line Construction

The article on the Riksgrans Railway by Mr. H. L. Kirker, in this issue of the JOURNAL, is most timely. The line construction described possesses features which make it desirable from many viewpoints. The Swedish Railroad Administration has spent a great deal of effort in engineering determination and in the development by actual test of methods of construction to be used as standards for their electrification program. Coal is expensive and difficult to obtain in Sweden, while enormous amounts of hydraulic power are available for development at moderate cost, so that eventually extensive electrification of the railway lines is assured.

The effort of their Railroad Administration has been to develop methods of construction at low costs with due regard to continuing low costs of maintenance. The construction they have in use provides for constant tension in the trolley wire irrespective of temperature conditions, special care being taken as well to control the contact pressure of the collecting members of the pantagraphs on the locomotives. The universal practice is to use a pair of current collecting devices so that practically no deterioration of the trolley wire occurs in service either through burning or through abrupt bending. The mechanical service on the main insulators is moderate and no excessive strains exist on the overhead structures or wire network. As a matter of fact, it is almost reasonable to expect that the deterioration of this trolley line will be somewhat on the order of that of a transmission line, due to the particularly favorable conditions for current collection.

There is much in this Swedish practice which may be used with profit under American conditions and, owing to the large number of track mile units involved in extensive electrification, methods which secure economy either in first cost or in continuing maintenance will be given more and more consideration by American engineers.

F. H. SHEPARD

On Visiting the Riksgrans Railway

H. L. Kirker

A FEW days before we left for Norway last October Mr. Franklin, manager of the Norsk Westinghouse Company, said we would visit the Riksgrans single-phase railway, up in the Arctic Circle, in Lapland, Northern Sweden. Mr. Franklin was over here in connection with a Norwegian State Railway electrification project, and I had been detailed to go to Norway with him to help lodge the tender and, incidentally while there, to look into railway electrification prospects.

Inasmuch as my passport read Norway only and as I rather expected to start back in December, my chances of seeing the Riksgrans Railway were rather scant. When I went down to the Norwegian consul's office to get my passport viseed, the day before the boat was due to start, it looked for a while as if I would not even get to Norway. The consul balked on giving me permission to land in Norway. My passport did not comply with some Norwegian regulation that had just recently gone into effect. However, Mr. Franklin took matters in hand, talked some vigorous Norwegian and finally got the vise that enabled me to board the only passenger steamer running between America and Norway, and to go ashore on arriving there.

FIG. 1—S.S. BERGENSFJORD OF THE NORSK-AMERICAN LINE
The boat on which the author sailed to Norway and Sweden.

We were booked to embark September 29. We actually left the dock Monday afternoon October 1st and dropped anchor after we had proceeded a few miles. We got under way the next afternoon and arrived at Halifax, October 4th, where we were censored by the naval officials. We left Halifax October 8th, and proceeded, in the direction of Iceland, for the Norwegian coast, north of the barred zone. We passed within sight of the Faroe Islands at sun rise October 15th, and were inside of the Norwegian three mile limit just at the northern edge of the submarine zone next morning. We steamed down the coast inside the three mile limit, touched at Bergen, missed any stray mines that might have been in our route and docked at Kristiania, Norway, Wednesday evening October 17th, in the rain. Kristiania is 60 degrees North, the same latitude as the southern tip of Greenland, but the Gulf Stream has a moderating influence all along the Norwegian coast.

I had traveled 4000 miles, but still had more than 1300 to go, if I visited Riksgransen. The sun was traveling south, the days in the northern latitudes were getting shorter and shorter, likewise the mercury column in the thermometers. I heard much of the Riksgrans Railway. It was regarded as standard construction by the government engineers, and the nearer the time of my departure came the more anxious I was to see that road. There were delays in connection with the Norwegian tender, and finally it became evident that I could not catch the December boat. My next chance to return was towards the end of January. Mr. Franklin and I accordingly began to make plans for a trip to Riksgransen.

The American consul general at Kristiania extended my passport to include Sweden, but getting permission from the Swedish Government to enter Sweden was quite another matter. Aliens were not wanted unless their visit would be a benefit to the Government. Fortunately Mr. Franklin, had previously lodged with the Swedish Government a tender for an electric locomotive for the Riksgrans. This negotation was still active and, in connection with it, Mr. Franklin asked permission for us to visit the railway. Mr. Ofverholm, chief electrical engineer of the Swedish State Railways, in complying with Mr. Franklin's request, stated that the date of our proposed visit corresponded with an inspection trip of his to the Riksgrans, and that he would accordingly accompany us. Moreover, the electrification of the Norwegian end of the Riksgrans road is contemplated by the Norwegian government, and Mr. Schreiner, chief electrical engineer of the Norwegian State Railways, had asked us to look over the Norwegian end of the road. These facts were submitted to the Swedish legation at Kristiania, along with application blanks properly filled out and accompanied with photographs. In due course the legation was authorized by the Swedish foreign office to vise my passport for a two weeks trip in Sweden, but only after my passport had been vised by the Norwegian officials to the effect that I could re-enter Norway from Sweden. All this took time, as I had to convince the head of the Norwegian secret service of the necessity of the trip, and he in turn gave me a memorandum to the department of justice where I was interviewed again and finally got a signed statement on my passport to the effect that I could return to Norway from Sweden. Norway

like Sweden had no food to spare on unnecessary aliens. On presenting my passport to the Swedish legation it was then formally stamped with permission for me to make a two weeks trip in Sweden, with stops at Kiruna and Stockholm.

On January 4th, Mr. Franklin and I left for Stockholm. We changed trains at the frontier. In the meantime we had been inspected by a Norwegian official who ascertained that we were taking no food out of Norway, and by a Swedish custom official who was on the look-out for dutiable goods going to Sweden, and finally by a Swedish officer who stamped our passports and gave us bread cards for one day and told us to report to the police department on arriving in Stockholm. We arrived at Stockholm next forenoon and reported to the secret service bureau as per instructions. About the first question asked Mr. Franklin was as to the whereabouts of that Englishman. He meant me. I was right there. My passport was scanned and I was checked against the picture and description on it. The letter from Engineer Ofverholm was displayed, and we were then pronounced "all right". We were given bread tickets for three days and were instructed that we were to leave Stockholm before the end of the day.

Having qualified with the police we called on Mr. Ofverholm, chief electrical engineer of the Swedish State Railways: As per arrangements he was expecting Mr. Franklin and an American Westinghouse engineer. On being presented to Mr. Ofverholm he suggested that he knew me. Then I recalled that he and another Swedish engineer had spent several days with me at the St. Clair Tunnel electrification on the Grand Trunk Railway in 1908. Mr. Ofverholm said that, a few days previous to our arrival, the Government secret service telephoned him asking him if he knew an American engineer named Kirker who was coming to call on him. He replied that he knew Kirker and that an American Engineer was coming along with Franklin, manager of the Norwegian Westinghouse Company, he did not know his name, but if it was Kirker he was safe—let him come along. It happened that a few hours before the police called up, Mr. Ofverholm, on looking through the October issue of The Electric Journal saw my picture in connection with an article I had in that issue. Hence his remembering me. Incidently, at the time I wrote the Journal article I told the editor that no author picture went with my article. Nevertheless, after I left Pittsburgh last September, the editor helped himself to my passport negative at East Pittsburgh. Now he claims that, had he not published the picture, I never would have gotten to Riksgransen.

Mr. Ofverholm showed us a working model of the Riksgrans locomotive and a map of the road. He also indicated some of the extensions that are on Sweden's electrification program. You will note from the map of Scandinavia that the line that runs up from Stockholm and on above the head of the Baltic and over into Finland and Russia, is intersected by a line that extends from the north end of the Baltic to the Atlantic. Lulea, Sweden, is the Baltic port and Narvik, Norway is the Atlantic port. The distance from port to port is 293 miles. Only 24 miles of the road are in Norway. The rest of it is in Sweden. An 80 mile division extending from Riksgransen on the Swedish-Norwegian frontier to Kiruna has been electrified. It is a 15 000 volt, single-phase, 15 cycle installation, which is the Swedish and Norwegian electric railway standard. The Riksgrans electric service was inaugurated in 1915, and work is now under way on an extension of the electrification from Kiruna towards the Baltic. Ultimately the 15 000 volt trolley will extend from the Baltic to the Atlantic and undoubtedly in due time south to Stockholm.

FIG. 2—ELECTRIC LOCOMOTIVE AND PASSENGER TRAIN AT ABISKOJOKK
Engineer Ofverholm in the middle.

Narvik, the Norwegian terminal, is an ice-free port notwithstanding its being 68° 30′ north. It is about 1000 miles by rail from Stockholm, which itself is 60 degrees N. Narvik was our ultimate objective, and Kiruna the southern terminus of the electric zone was our immediate aim. Kiruna is 880 miles from Stockholm. The electric locomotive shops are located here, also one of the railway transformer stations.

On the evening of January 5th, Mr. Franklin and I left Stockholm in company with Engineer Ofverholm and his assistant Mr. Warodell. We arrived at Kiruna Monday noon January 7th. Enroute Engineer Ofverholm had explained to us the details of the trolley construction and of the electric service. We also talked about the weather. We had expected the weather to be cold, but it exceeded our expectations. We ascer-

tained that our trip coincided with a Swedish blizzard. Nevertheless, while our steam road trip was not a joy ride and there was no heat to spare and food was restricted to a narrow bill of fare, the ride was not exactly uncomfortable. When we stepped on the platform at Kiruna at noon the sun was just below the sky line of hills on the southern horizon. The thermometer on the platform registered—33 degrees C. We were at the beginning of the electrical zone. However, we were more immediately interested in the railway hotel. Our train was four hours late and we had had no breakfast.

While the twilight still lasted, Engineer Ofverholm took us up the line on an electric locomotive on an inspection trip, then to the transformer station, then to the locomotive shops. After dinner we were given an exhibition of the performance of the locomotive hauling an ore train at very low speed over the track scales. Still later in the evening Mr. Franklin and I, with Mr. Warodell, set out for the Porjus power plant, 96 miles away by rail, where we arrived late in the forenoon of

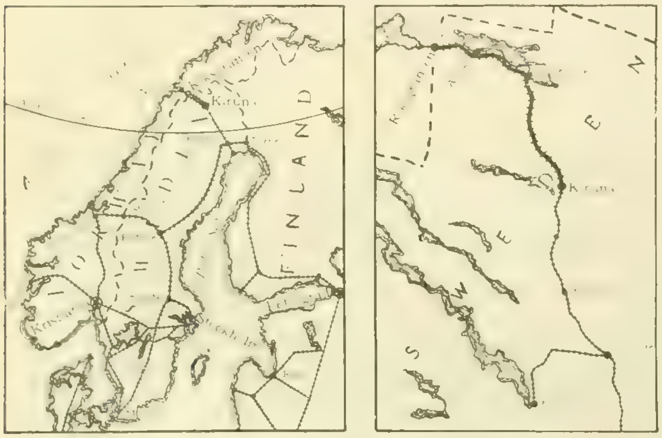


FIG. 3—MAP OF NORWAY AND SWEDEN
Showing electrified section of the Riksgräns Railway between Riksgränsen and Kiruna.

the next day. The railway gets its power from the Porjus plant which is at the end of a stub line that leaves the main line 63 miles south of Kiruna.

Steam railroading was rather difficult on account of engine trouble due to low temperature and on account of hot boxes due to poor oil. The temperature was low at Porjus. The engineer in charge of the power plant said that the minimum thermometer registered—50 degrees C. the previous night. We did not put in much time inspecting the dam. The power plant itself was warm enough. The dynamo room, like that of Snoqualmie plant in the state of Washington, is an excavation in the rock below the falls. The installed capacity of the plant is 50 000 horse-power in 12 000 horse-power units. The railway power is generated at 4000 volts, single-phase, 15 cycles and is transmitted at 80 000 volts single-phase.*

The 15 000 volt trolley with its automatic slack adjuster was the part of the installation in which we were especially interested. We did not tarry long at Porjus, but through the courtesy of our railway friends were able to reach Kiruna on the evening of the 8th, where

FIG. 4—POWER HOUSE AT PORJUS

we got a good night's sleep in the railway hotel. We had had two hours in a hotel the night before. The previous three nights had been spent in sleepers where we had re-enforced the blankets with rugs, overcoats and newspapers. The railway hotel at Kiruna is an excellent one. Among other things we had there was real butter—thanks to Engineer Ofverholm and to Engineer Bildt of the Kiruna mines. We were also supplied with bread tickets for the duration of our trip.

The next day Mr. Franklin and I rode in the front end of an electric passenger locomotive, in company with Mr. Ofverholm and Mr. Warodell, over the entire electric zone. We left Kiruna at 11 A. M. with only a glittering evidence of the sun's presence below the southern horizon. The colors were as brilliant and as varied as those we had seen at the Faroe Islands. The sun was not visible during the trip, but there was plenty of light. Occasionally we would get

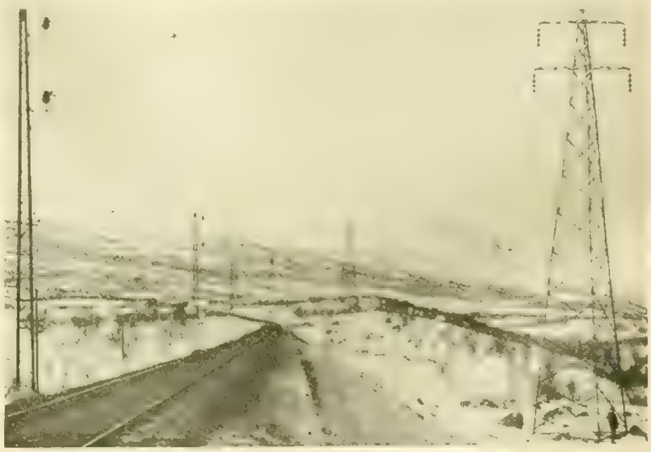


FIG. 5—TYPICAL VIEW IN THE ELECTRIFIED ZONE

a red glow on the south side of some of the taller peaks. Snow blanketed the entire landscape. We passed through several snow flurries. On the whole, however, we had a fine view of the trolley construction in all its phases. We saw it on tangents and curves, at

*The power plant and the transmission line and the electric railway have been described in the technical press. A very complete illustrated description of the whole electrical installation, power plant, transmission line and railway has been published by the Allmanna Svenska Electric Company which company built most of the electrical equipment.

stations and yards and in tunnels and snow sheds. We were impressed with its lightness and simplicity.

Lattice steel poles are used. They are set in concrete to the depth of about two meters and range from 8 to 11 meters in length. A ten meter pole weighs 266 kg. The poles are usually set on the outside of curves. The spacing on tangents is 52.5 meters. There is not an anchor rod nor a guy cable on the entire system. The bracket arm construction is hinged like a gate for swinging in the horizontal direction. The insulators are carried on brackets at the pole. The insulator pins are the pivots on which the bracket arms swing. The fact that the insulators are at the side of the track away from the blast from the steam locomotive stacks is a factor of safety when steam and electric locomotives use the same track.

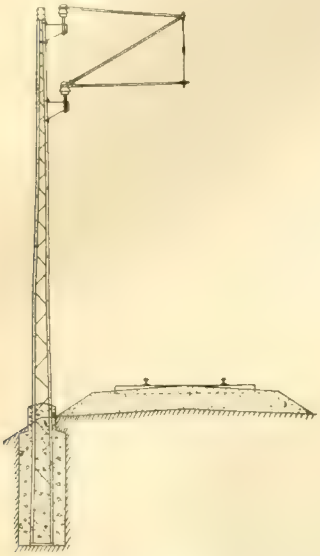


FIG. 6—STANDARD TROLLEY POLE AND BRACKET CONSTRUCTION

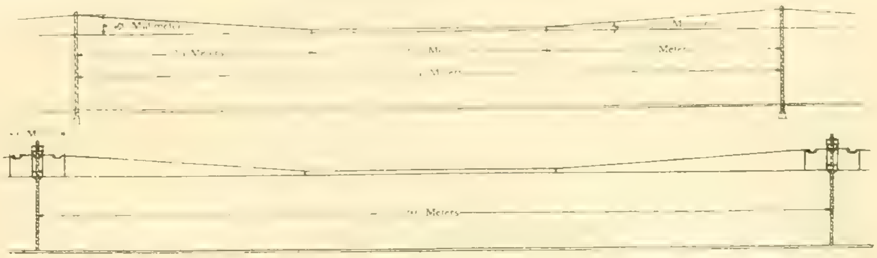


FIG. 8—STANDARD TROLLEY WIRE SUSPENSION
On Tangent (upper) and at Station (lower).

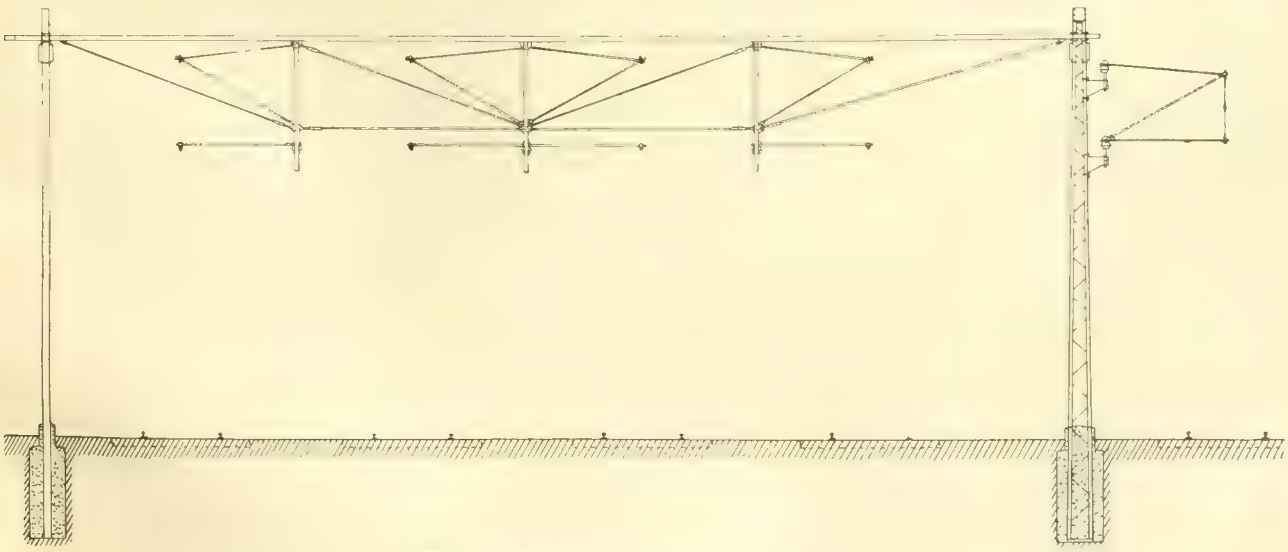


FIG. 7—SECTION OF FOUR-TRACK CONSTRUCTION
With extra side bracket for fifth track. A side view of this construction is shown in Fig. 8.

The trolley hanger at the bracket is linked at the middle, and the lower bracket arm can swing in the vertical direction. This arrangement gives an elastic support at the bracket and allows a slight upward movement at the trolley wire when the pantagraph bow passes under the bracket. There are but two intermediate hangers and they are solid and clamped rigidly to both trolley and messenger. The spacing between hangers on tangents is 17.5 meters. The linked hanger at the brackets is 1400 m.m. long and the solid intermediate hangers are 200 m.m. long. The upward pressure of the pantagraph bow on the trolley wire is about 7 kg.

The messenger is stranded copper of 50 sq. m.m. section. The trolley is grooved copper of 80 sq. m.m. section. The hangers are copper. The fittings are bronze. The bracket arm tubes and fittings are galvanized.

The messenger cable is drawn up to a tension of 5.6 kg. per sq. m.m. or 280 kg. for the 50 sq. m.m. messenger. The trolley is drawn up to a tension of 8 kg. per sq. m.m. or 640 kg. for the 80 sq. m.m. trolley. The trolley hangs practically level. From personal inspection I found it to be slightly higher between brackets than at the brackets. The combined tension of trolley and messenger is 920 kg.

The cross-section of the messenger is smaller than the cross-section of the trolley. This is one of the features of the installation. The idea is to minimize the trolley deflection due to wind pressure, by restricting the messenger swing. A long span of big messenger cable presents a considerable amount of surface for side wind pressure. The bigger the messenger the greater the side swing will be. The swinging messenger necessarily carries the trolley with it. If the messenger had

no side swing the trolley deflection due to wind pressure would be small; it would be limited by the trolley hangers. With a small messenger and a big trolley wire the side pressure comes mainly on the trolley wire. Moreover the gravity pull of the trolley wire is relatively big. The net result therefore is that the combined side swing of messenger and trolley is small.

FIG. 9—LINE CONSTRUCTION IN RAILWAY YARD

Another feature of the installation is the use of copper for both messenger and trolley. This arrangement simplifies the automatic slack adjustment problem. Automatic slack adjustment is indispensable on a road subject to the temperature variations that obtain on the Riksgrans. This is especially true as regards the daily variations that occur during the summer months. The Swedish Engineers have evolved a simple and satisfactory automatic slack adjuster. It is based on the use of copper messenger and trolley, swinging bracket arms, short sections in both messenger and trolley with air section brakes, and a dead end anchor weight at each end of each section. The normal length of a section is 1365 meters on tangents.

The trolley and messenger terminate at a common strain insulator, and the strain insulator is attached to a chain that carries the anchor weight. The chain is dead ended at the first trolley pole beyond the air section brake. The arrangement of the pulleys is such that the travel of the weight is twice that of the amount of slack it controls. The anchor weighs 460 kg., which is half the combined tension of the trolley and messenger. I understand that the maximum travel of the anchor weight on the Riksgrans slack adjuster is approximately one meter. There are necessarily two trolley poles at the air section brake. A bridging switch preserves the continuity of the trolley circuit.

There is a double bracket arranged in *V* at the middle of each trolley section. The object of this double bracket is to localize the slack to a half section in the event of a trolley or messenger failure. A break on either side of the double bracket will allow the double bracket to swing a few degrees in the other direction before equilibrium is attained, after which the double bracket acts as a temporary anchor and keeps the trolley over the track in the half section opposite the break.

Double track is cared for by single poles carrying brackets on two sides. For three or more tracks

FIG. 11—TYPICAL POLE AND STRAIN INSULATORS

bridges are used. The bridges are of light and simple construction. Trolley poles are used for bridge columns. The trusses are a development of the "Mechano" toy construction. The bracket arrangement on bridges is slightly different from the pole brackets. The hinged principle is retained, but the trolley pull off is the only member that is insulated. Strain insulators are cut into the messenger cable on either side of the messenger arms and there are two hangers, one at each strain insulator, on the live side of the messenger cable. This arrangement will probably be modified in future installations by carrying the messenger over the bridge on a roller insulator, which arrangement will avoid cutting the messenger at bridges and eliminate the two strain insulators that the present construction necessitates at the bridge. A three-track, 15 meter truss weighs 800 kg. A 30 meter truss weighs 1000 kg. The maximum span without intermediate support is six tracks. The standard arrangement is to use the trolley poles or bridge columns for dead ends.

In yards and at stations where the trolley section approximates the length of the standard section, the automatic slack adjuster is used at each end. On the shorter sections the automatic slack adjuster is applied at one end of the section only. The short length of the standard section, 1365 meters, the use of deep sags in the messenger cable, and the use of copper in both messenger and trolley and the use of automatic slack adjusters enable the light bridge construction to be used. This light construction, with moderate tension on the trolley and messenger, coupled with the fact that the poles and columns are set in concrete with a depth of about two meters enables anchor rods and cables to be entirely dispensed with. The use of light lattice poles and the absence of anchor rods offers minimum of ob-

FIG. 10—DIAGRAM OF SECTIONS BETWEEN TWO SLACK ADJUSTERS

struction to the view ahead of the locomotive, which is a desirable operating condition.

The average cost of the trolley construction erected in 1912 and 1913 was approximately $2000 per kilometer exclusive of track bonds and track transformers.

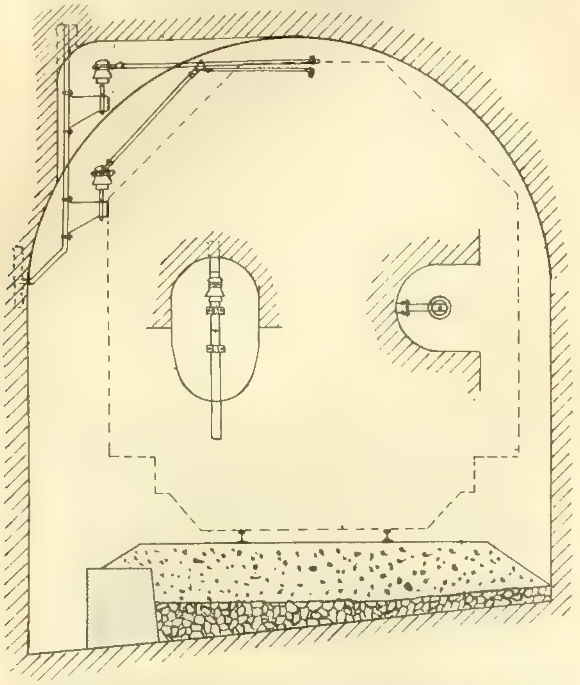


FIG. 12 TYPICAL TROLLEY WIRE SUSPENSION IN A TUNNEL

It was a contract job and, notwithstanding the low price that obtained at that time for steel, copper and labor it is probable that the contractor made no profit on the job.

The electric service was inaugurated on the Riksgrans in 1915 and, according to all indications and to all reports, it is a success. The trolley construction

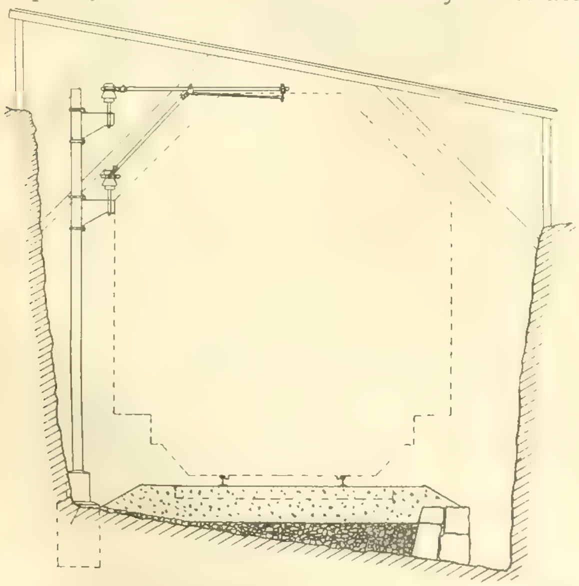


FIG. 13 TYPICAL TROLLEY WIRE SUSPENSION IN A SNOW SHED

with its automatic slack adjuster is the especially interesting part of the installation. The maintenance of the overhead construction is said to be very small. I saw no evidence of wear on the trolley wire. This is due on part to the pantagraph shoes, made up of ninety percent aluminum and ten percent copper. Arcing that might result from the collection of heavy currents is minimized by the standard practice of using both pantagraphs on the locomotive. There are in all 21 electric locomotives. Engineer Ofverholm had told me about the pantagraph shoes and automatic slack adjuster when he visited the St. Clair tunnel in 1908. The slack adjuster idea did not appeal to me strongly at that time. However, I found that three years of service on the Riksgrans had demonstrated that it meets the requirements under the temperature conditions that obtain in northern Sweden. The Riksgrans automatic slack adjuster is a simple means of caring for a very annoying trolley problem.

The electric service on the Riksgrans is more popular than the steam service, especially in the winter when the superiority of the electric over steam locomotives is most pronounced. When our electric locomotive

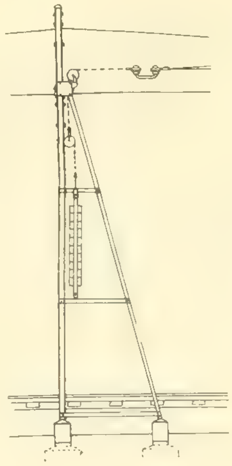


FIG. 14 — SINGLE SLACK ADJUSTER FOR TROLLEY

FIG 15—COUNTER WEIGHTS FOR EQUALIZING STRAINS

picked up the train at Kiruna the train was late. Engineer Ofverholm cheerfully assured us that the train would make up time in the electric zone. We did. We arrived at Riksgransen, the northern terminus of the electric zone at 1:43 P. M., where a Norwegian steam locomotive was substituted for the electric. Riksgransen is about 68 degrees N. and approximately 1700 ft. above sea level. The way the wind blew the powdered glass brand of snow along the station platform was harsh. Changing locomotives here in the winter does not increase the popularity of the steam service with the railway men. We did not remain long on the platform but got something to eat, qualified with the custom house officers and boarded the coach for Narvik, the Norwegian port on the Atlantic, which is only 24 miles from Riksgransen by rail but more than that by climate. Its temperature was not much below

freezing. As already stated, it is an ice-free port. We arrived at Narvik at 3:30 P. M., after dark. My passport was again scanned and stamped. Narvik being at sea level on an east and west fjord has long winter nights. Its first sun rise is sometime in February. Some one suggested that we go by boat from Narvik to Bergen, then by train from Bergen to Kristiania. A trip down the choppy Norwegian coast in a small passenger steamer in January did not appeal to us. The suggestion was quickly disposed of. We never had any intention of returning by any other route than the one by which we came.

We left Narvik about 6 P. M. on January 9th. At Riksgransen we passed through the custom house again, and an electric locomotive was substituted for the steam one. At Kiruna, Engineer Ofverholm joined us and traveled with us to Stockholm where we arrived on January 11th, after 48 hours of travel from Narvik. Engineer Ofverholm expects to see the day when electric locomotives will haul passenger trains all the way

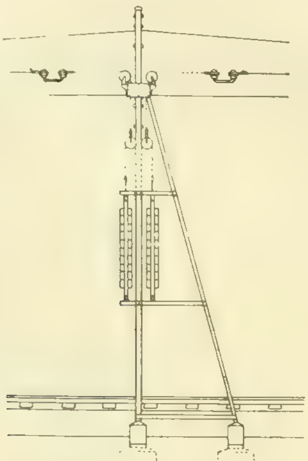


FIG. 16—DOUBLE-SLACK ADJUSTER

between Narvik and Stockholm and make the run in about half the time that we took on our return trip.

Enroute and later at his office, Engineer Ofverholm supplemented the data he had already given us on the Riksgrans. The hinge trolley construction with its automatic slack adjuster was arrived at by the Swedish engineers after deliberate study and trial of numerous arrangements. It is the Swedish Government standard and is regarded favorably in Norway. As it becomes more generally known it will undoubtedly be applied in other countries. It is especially adapted to steam railway main line electrification projects.

My passport was stamped again at the frontier and had to be viseed by the American Consul at Kristiania before I could board the boat for New York. On the return trip we made the run from Kristiania to New York in eleven days. The passage was without incident. We met one steamer, a tramp freighter, and had several displays of northern lights. My passport was cancelled at the New York dock but I was allowed

FIG. 17—ANCHOR HALF WAY BETWEEN SLACK ADJUSTERS

to retain it as a souvenir. In due course the data I brought back with me was passed through the custom

FIG. 18—SECTION BREAK AND BRIDGING SWITCH

house, and thanks to my Scandinavian friends I am able to give the foregoing description of the Riksgrans trolley construction.

A Modern Motor-Driven Lime Plant

A. E. Truesdell and C. T. Maynard

THE VERMONT Marble Company has for years been carrying on the largest marble quarrying operations in the world and, while a vast amount of valuable stone has been taken from the quarries, there has also been a large amount of waste, consisting principally of small and unsound blocks. While some of this waste has been used for crushed stone, etc., there was still a large amount of it to be disposed of. Nearly three years ago, experiments were made on different grades of marble to determine what grade of lime could be obtained by burning this marble. The tests showed up so well that it was decided to build a modern, well-equipped lime plant. As a result, work was begun in the summer of 1915 on a plant, designed by the Fuller Engineering Company and erected largely under their direction, and in the early spring of 1916 the first lime was produced.

The plant is located near the extensive West Rutland quarries and sidings run on both sides of the plant, so that coal and waste marble can be brought in, as well as the finished product taken out. The main building is of steel, 420 feet long and 40 feet wide. A producer house, 80 by 30 ft., lies just east of the main building and the office, coopers' shop, and transformer station are just west of the main building.

Power is brought from the Vermont Marble Company's transmission system, to the 25 by 35 ft. transformer station, built of waste marble, over two 11 000 volt, three phase, 60 cycle lines, where it is stepped down to 460 volts by three 200 k.v.a. self-cooled transformers. These two 11 000 volt lines are normally in phase, so that the bank of transformers can be shifted from one line to the other without any interruption of service. This arrangement was necessary to avoid shut down of the plant when it was necessary to change insulators or make repairs to either line. The transformers are of large enough capacity so that two connected in open delta will not be seriously overloaded at any time. The fact that power must not be off for more than a few minutes, owing to the liability of warping the large revolving kiln, necessitated the extra precaution of maintaining two power lines which are normally in phase but may be fed from either of two entirely different power systems, if one line or system is out of service.

Direct current for the 25 ton traveling crane is furnished from a 230 volt motor-driven generator at the main West Rutland substation, nearly one half mile south of the lime plant. All motors, except those for the crane, are 440 volt, three phase, 60 cycle induction type. Lights for the plant are furnished by a 460 volt to 115 volt lighting transformer.

The plant and its operations can best be understood by following the product through from the time the stone is delivered to the plant on flat cars loaded with waste marble from the nearby quarries and blockpile.

FIG. 1—VIEW OF LIME PLANT OF THE VERMONT MARBLE COMPANY

CRUSHING DEPARTMENT

The material comes to the plant in miscellaneous sizes and if over 12 inches in thickness is handled by slings and crane into the 60 by 48 jaw crusher. From the jaw crusher it passes by gravity with sizes below 12 inches through a No. 6 McCully gyratory crusher, set to reduce down to two inches and less. The material is then elevated and screened. The screen rejection is run through a set of 36 by 16 Superior rolls, to reduce it to one half inch thickness or less. All the material is then elevated and conveyed into storage or kiln bins, whence it can be drawn as desired.

This department has eight motors of 272 hp total and can reduce 25 tons of stone per hour from blocks of 150 cubic feet to stone one half inch thickness and less.

MOTOR ON	HORSE-POWER
Jaw crusher	150
Gyratory crusher	50
No. 1 elevator	7.5
Screen	7.5
Rolls	35
No. 2 elevator	10
Conveyor	5
No. 3 elevator	7.5
Total	272.5

BURNING DEPARTMENT

The crushed stone is fed automatically from the

kiln bin into the kiln by a cradle feeder. The kiln is after the familiar cement design, eight feet in diameter, 120 ft. long, installed with a four percent pitch. It is belt driven by a 30 hp variable speed motor, geared to give ten speeds from 0.5 to 1.5 r.p.m., as desired.

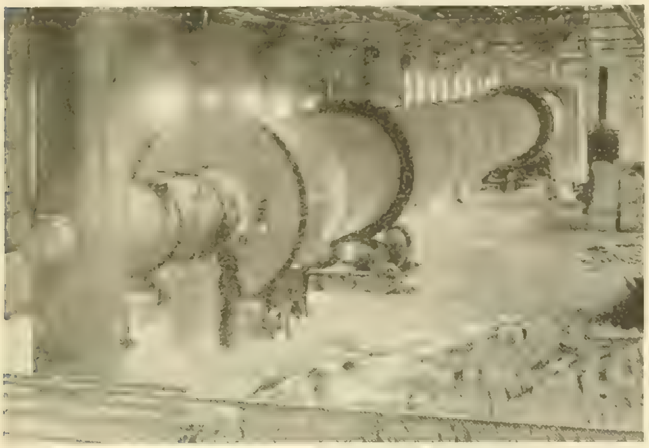


FIG. 2—GENERAL VIEW OF KILN
A second kiln will be installed at the right of the one shown.

Producer gas is introduced through a flue into the lower end of the kiln and in burning furnishes the heat for calcining the stone as it gradually rolls through the revolving kiln. A temperature of 2200 degrees F. is maintained in kiln, which drives off the CO_2 from the stone, leaving the quicklime. The hot lime drops from the lower end of the kiln into a revolving cylinder, in passing through which it is cooled by the draft of air on its way into the kiln to support combustion. The cooled lime is elevated from the discharge of the cooler and after screening is deposited into large storage bins.

The producer gas is made as used in a 10 foot Chapman mechanical gas producer from Pennsylvania gas coal. The coal is discharged from hopper bottomed cars through a coal crusher by conveyor and elevator in-

FIG. 3—KILN DRIVEN BY 30 HP, 720 R.P.M. MOTOR

to a large storage bin, or into the producer bin. From the producer bin it is fed as needed by the attendant. The producer is blown by a steam jet, resulting in a lean gas, containing over 50 percent nitrogen, which in burning gives a mellow flame. The gas is conveyed into the kiln by a heavy brick lined flue having suitable openings for cleaning. Producer gas is used as it gives a long flame of comparatively low temperature and of considerable volume. The use of gas is preferable to coal where a clean lime is desired.

FIG. 4—BAGGER OPERATED BY 15 HP INDUCTION MOTOR

The kiln operation is checked by a Bristol recording tachometer, as to speed and output, while the quality is recorded by a Truesdell automatic sampler. This department has nine motors and produces 60 tons of lime per 24 hour day.

MOTOR ON	HORSE-POWER
Coal crusher	10
Bin conveyor	5
Coal elevator	7.5
Producer conveyor	5
Producer drive	5
Kiln	30
Dust conveyor	5
Cooler	10
Lime elevator	10
Total	87.5

HYDRATING DEPARTMENT

From one of the storage bins containing *CaO*, lime is automatically drawn for hydrate manufacturing. The

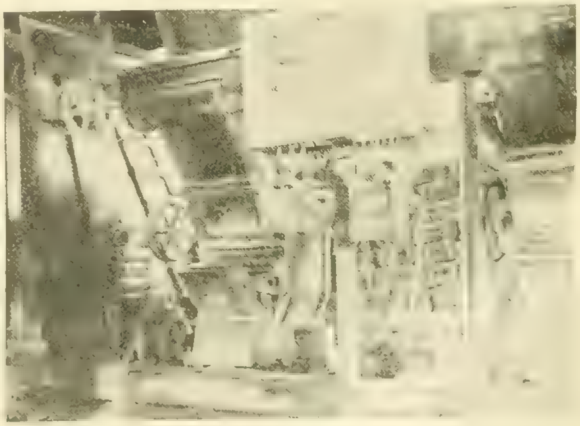


FIG. 5—FINE PULVERIZING MILLS
Driven by two 5 hp, 1800 r.p.m. motors.

Kritzer process is used which essentially is mechanical stirring of the mixture of lime and water through 75 feet of 24 inch piping. If the proportions of lime and water are correct, the dry, fluffy, white powder of CaO_2H_2 results at the end of the stirring tube. As this

powder may contain some grit or other impurities, it is air separated by means of Raymond mills, cyclones, and canvas tubes into Vermarco hydrate and Superfine hydrate, while the impurities are rejected. Some idea of the fineness of the hydrate may be had from the statement that less than six percent is retained on a 200 mesh screen, while the Superfine is still finer. This material is packed into paper bags by a Bates bagging machine. This department has six motors and can produce 4 to 5 tons of hydrated lime per hour.

MOTOR ON	HORSE-POWER
Hydrator	15
Raymond mill	5
Raymond mill	5
Separating fan	20
Separating fan	20
Bagging Machine	15
Total	80

Besides the equipment described, the plant has a cooper shop with a capacity of 500 barrels per day. Barrels are delivered into the kiln building automatically as needed by a barrel elevator and run. The elevator is run by a two hp motor. Storage buildings and shed for care of machinery parts, barrel stock, barrels, tools, etc., complete the layout.

MISCELLANEOUS MOTORS	HORSE-POWER
Air Compressor	15
Pump in Cooler Pit	3
Pump in Quarry Pit	2
Barrel Elevator	2
Total	22

There are in the plant 27 induction motors with a total horse-power rating of 462 and three direct-current series motors on the crane with a total of 55 horse-power. The induction motors are squirrel-cage type except the 150 hp jaw crusher and the 30 hp kiln motors, these two being of the wound-secondary type, the crusher motor for starting duty and the kiln motor for continuous running at any point between one third and full speed. The plant uses between 25 000 and 30 000 kw-hrs. per month.

As the raw material is of exceptional purity, the lime manufactured is of high grade. Unlike the usual lump lime, so familiar to all, it is granular like sugar and since it is burned at a comparatively low temperature, it slakes very rapidly, so quickly in fact that it is advisable to stir the lime into the mixing water in order to keep the slaking temperature reasonable. In the market it is very favorably known on account of its smooth working putty, whiteness, and causticity.

The New 45th Street Substation

of the United Electric Light & Power Co., New York

Roy R. Kime
New York District Office
Westinghouse Electric & Mfg. Company

As a general rule substations are located in out-of-the-way places where few restrictions hamper their design. Of special interest, therefore, is the new 45th street substation of the United Electric Light & Power Co. because of the unusual conditions which had to be met in its construction and arrangement. This substation serves the area between 27th and 82nd St., and the Hudson and East Rivers, a district that is thoroughly built up and inhabited by hundreds of thousands of people. In order to place it near the center of load, it was necessary to select a site among residences where real estate values are very high and where quiet operation and freedom from vibration are essential.

On approaching the station one is immediately struck by two peculiarities, both of which are due to the exigencies of its situation. One is the narrowness of the structure and the other the space that has been left between each side wall and the adjoining building, as shown in Fig. 1. The building is narrow because it is confined to a plot intended for a single moderate-sized dwelling. The dimensions of the floor plan are 24 by 100 feet, which is a very cramped space for a building that will ultimately contain 12 500 k.v.a. of electrical apparatus. Yet, as can be seen from the illustrations the interior, though conspicuously constricted, is in no sense crowded. Careful designing and the utilization of every single cubic inch of space were, however, required to obtain this result. The floors and walls consist in reality mainly of cables, conduits and pull boxes; and some of the apparatus installed had to be specially designed in order to take up a minimum amount of room. The capacity is ten kilowatts per cubic foot, which is about double the usual concentration.

The space between the walls of the station and the adjoining houses is one of several precautions that have been taken to avoid disturbing the neighbors with noise and vibration. It was decided that an air space would be preferable to the use of deadening material, to retain the noise within the building; and in order to guard against contact at any point, aprons were carried along as the brick work progressed, which established the proper distance between the walls and kept out pieces of brick, mortar and other material that might have fallen down the openings.

Every effort was also made to eliminate noise at its source. All rotating apparatus was arranged to operate as quietly as possible, and in addition, sound insulators consisting of alternate layers of cork and sheet iron were placed under the transformers, induction regulators and synchronous condenser. The condenser, being the machine most likely to cause disturbances, was mounted on a foundation that extends to bed rock and is in no way connected with the rest of the building,

thus preventing the vibrations of this machine from being transmitted to and magnified by the steel frame work.

As an illustration of what the Company had to contend with, it may be mentioned that when the station was first placed in operation, before all the refinements were perfected, the neighbors on both sides promptly threatened to move out. Since the completion of the work, however, no serious complaints have been received.

LAYOUT OF THE STATION

The building, which is 46 feet high above the sidewalk, has three floors and a basement. On the main floor are the switchboard and its operation desk, the main transformers, the induction feeder regulators, a synchronous condenser, and a motor-generator set. On

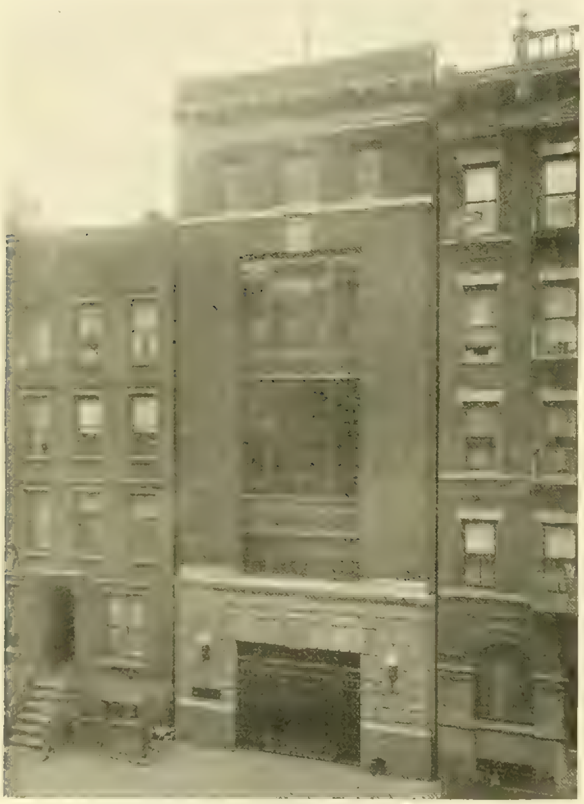


FIG. 1—45TH STREET SUBSTATION
Of the United Electric Light & Power Co., New York. Note the sound-deadening clearances between the substation and the adjoining buildings.

the two upper floors are the oil circuit breakers with their accessories and the busbars. In the basement are vaults containing the connections for the apparatus on the main floor, the motor-driven blowers for ventilating the transformers and regulators and an air washer.

At present, the station has three 7500 volt incoming feeders and ten 3000 volt outgoing feeders, but is designed for an ultimate capacity of five incoming and twenty outgoing feeders. Arrangements have also been made to raise the incoming voltage to 15 000 in the future, and all high-tension apparatus is insulated for this higher voltage and all the transformers are provided with taps so that the change-over can be made with little trouble and with no additions to the present equipment.

The load is mainly residence and theatrical lighting, the maximum power load being but one-third of the maximum lighting load. The power load is nearly constant throughout the day, while the lighting peak occurs at the close of the business day in winter and an hour or two later in summer.

OPERATING ARRANGEMENTS

Continuity of operation under all imaginable conditions is the ideal on which the plan of the station was

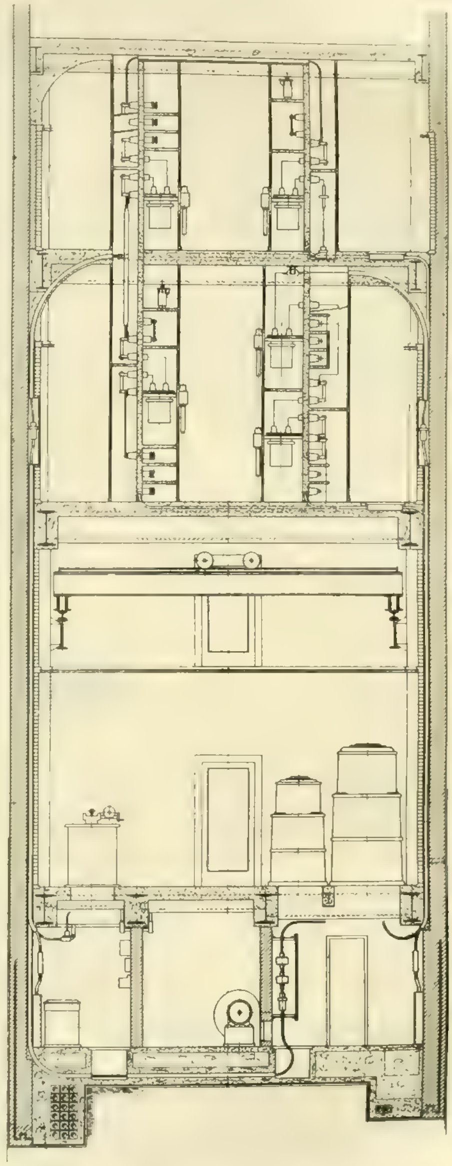


FIG. 2—CROSS-SECTION OF THE BUILDING
Showing general layout of the substation.

based. Each piece of apparatus is safeguarded as completely as possible; spares are provided for all vital devices; any desired combination of incoming high-tension and outgoing low-tension circuits can be obtained; and any piece of apparatus and any circuit can be cut out of service without interfering with the operation of the station.

Three-phase, 62.5 cycle current is transmitted from the United Company's 201st street power house to the Waterside bus, from which tie feeders about 1.5 miles

long run to the 45th street station. These feeders terminate in separate manholes outside the station so that the burning out of one will not affect the others.

The feeders, in the form of 350 000 cir. mil, lead-covered cables, enter the basement of the station through tile ducts and run up the west wall in separate fiber conduits to pull boxes in the wall of the second floor, where the lead sheathes end in pot-heads. From each pot-head a cambric and braided cable runs to a 600-ampere oil circuit-breaker with disconnecting switches on both sides.

Each line now divides into two branches, as shown in Fig. 3, with a 600 ampere oil circuit-breaker with disconnecting switches in each branch. One branch runs to the high-tension side of a main transformer and the other to a common high-tension bus. Ordinarily each line from feeder to transformer is kept independent, but by means of the bus, any or all of the transformers can be supplied from the other feeders should

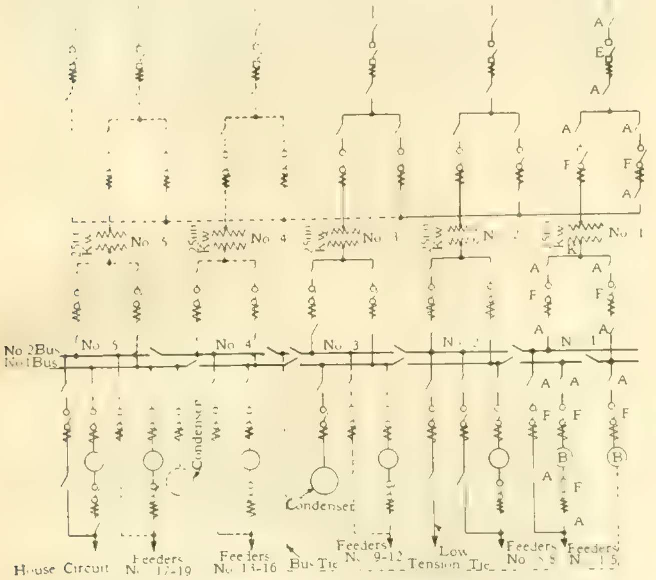


FIG. 3—SCHEMATIC DIAGRAM OF BUS TIES AND FEEDERS

A—Disconnecting switch; *B*—Regulator; *E*—Type C automatic oil circuit breaker; *F*—Type E automatic oil circuit breaker; *K*—Transformer.

one feeder be cut out; while on the other hand should any transformer be cut out the other two can be supplied from all three feeders.

From the secondary of each transformer, a line provided with a 1200-ampere circuit-breaker runs to each of two bus-bars, called No. 1 and No. 2 respectively. From each bus, a line runs to each outgoing feeder, the difference between these last two lines being that in the line from bus No. 1 there is an induction regulator, with a circuit-breaker on each side, while in the line from bus No. 2 there is a circuit-breaker only. Thus each feeder can be supplied either through a regulator or from a low-tension bus direct. A tie with a regulator connects the two busses, and provides means for regulating any feeder while repairs are being made to the regulator or circuit-breaker in the line from bus No. 1 to that feeder.

Both low-tension busses can be divided into sections, each connected with a transformer and with several outgoing feeders, so that any group consisting of a transformer and its outgoing feeders can be operated independently of the rest, or can be cut out if desired. The foregoing arrangement provides a very high degree of flexibility and permits the various elements to be grouped into a large number of different combinations.

FIG. 4—GENERAL VIEW OF MAIN FLOOR OF SUBSTATION
Showing synchronous condenser, switchboard, control desk and induction regulators.

CIRCUIT BREAKERS

The bus-bars, circuit breakers and their accessories are mounted in concrete compartments and are protected by light asbestos-board covers mounted in steel frames. The barriers between the circuit breakers are 3.5 inches thick, and those between the disconnecting switches are two inches thick.

The circuit breakers for the incoming feeders are of standard Westinghouse construction, but the type E circuit breakers, for both the high-tension and the low-tension circuits have been modified according to designs by Mr. McCoy of the United Company. The standard type E circuit breakers are made up of single-pole units, each with its own supporting frame and contact-operating mechanism. In the 45th street station units, however, a special base has been provided which carries all the circuit breaker parts, and all closing levers are connected to a single shaft. When the cir-

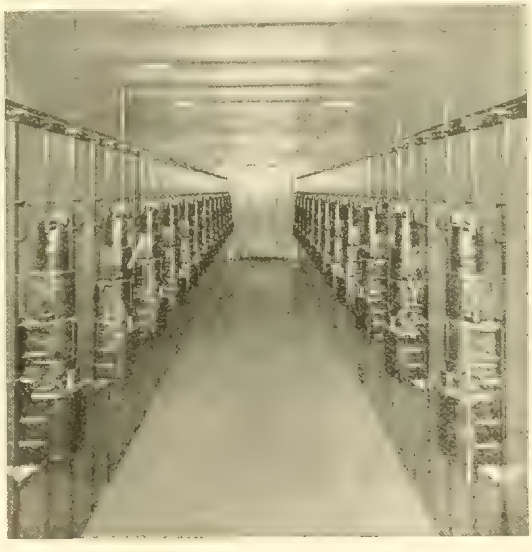


FIG. 5—OIL CIRCUIT-BREAKER AISLE
Each circuit-breaker is mounted in a concrete compartment with only the cast-iron casing of the operating mechanism and the relays exposed.

cuit breaker is in place, the only part that shows is the cast-iron casing of the operating mechanism, all live and moving parts being concealed behind covers.

TRANSFORMERS

There are at present three banks of T-connected air-blast transformers, but two more will be added when needed. Each bank consists of a 2000 k.v.a. unit for lighting purposes and a 500 k.v.a. teaser for power, connected as shown in Fig. 8. The primary winding of the teaser transformer is wound for 86.6 percent of the voltage of the main transformer, giving a standard three-phase T-connection. The teaser secondary is wound for 70.7 percent of the main transformer secondary voltage giving 2100 volts between phases and 3000 volts between the two outside wires. The power load is supplied at 2100 volts in the usual manner. The lighting load is obtained from the two outside wires at 3000 volts, and is transformed through the main unit practically as a straight single-phase load. The connections between the transformer units are such that the teaser is in service only when two-phase power is being used. Two transformer banks are at present sufficient to handle the full load, so that the third is a spare.

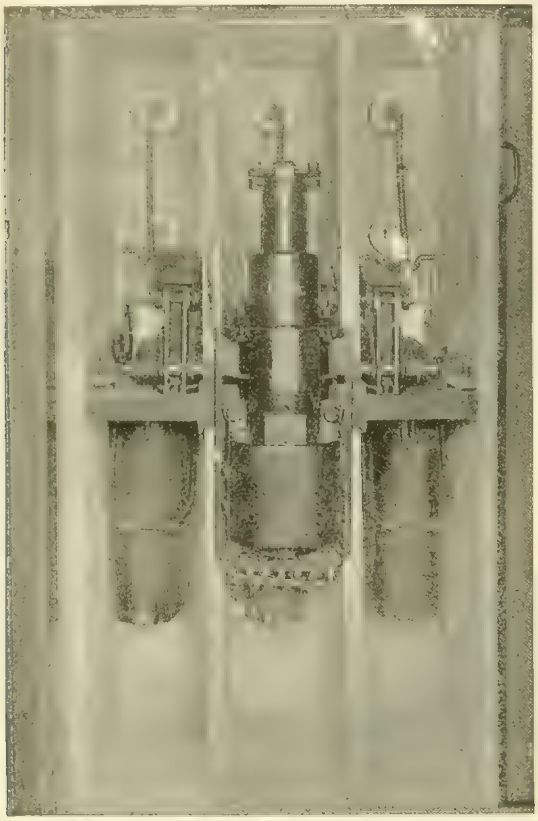


FIG. 6—DETAIL VIEW OF MODIFIED TYPE E CIRCUIT BREAKER

All wiring enters the transformers from vaults in the basement below. This arrangement makes all connections easily accessible and adds greatly to the appearance of the main floor. Each transformer bank has its own ventilating blower, which starts automatically when the transformer is energized; but if any one of the blowers is out of service, air can be supplied to its transformer from the other blowers.

REGULATORS

Eleven 85 k.v.a. air-cooled induction regulators are at present in operation, ten controlling outgoing feeders and one for use in the tie between the two low-tension busses, but ten more can be installed to meet future requirements. These regulators have a range of ten percent above and ten below normal voltage. Line-drop compensators are installed in connection with the regulators, which provide for a normal voltage of 2750 volts across the outside lines of each feeder at the center of distribution. In order to conserve space, the operating mechanism on the top of the regulators has been so arranged that none of it projects beyond the case.

FIG. 7—THREE T-CONNECTED, AIR-BLAST TRANSFORMER BANKS

All the leads to the regulators run up from a compartment in the basement below. The regulator relays and the compensators are also mounted here. A large ventilating blower forces air into this compartment from whence it passes out through the regulators.

SYNCHRONOUS CONDENSER

To assist in correcting the power-factor and in stabilizing the voltage of the system, a 1000 k.v.a. synchronous condenser is connected to low-tension bus No. 1. A second condenser will be added when the contemplated additions to the station are made. The condenser is provided with a special regulator which has two elements; a voltage element which responds quickly to voltage changes and prevents rapid variations of the bus voltage; and a current element, which operates to maintain an approximately constant current in the condenser, bringing the current very slowly back to normal with changes in voltage. The object of this combination is to correct quickly for sudden changes of voltage and to allow sufficient time for the feeder regulators to readjust themselves to any new voltage on the bus.

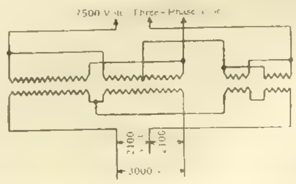


FIG. 8—DIAGRAM OF CONNECTIONS OF TRANSFORMER BANKS

The condenser has a direct-connected 27.5 kw, 220-volt exciter which also acts as a starting motor. Direct-current for starting (and for other purposes, such as operating relays, switches, etc.) is supplied by a similar direct-current generator operated by an alternating-current motor. The exciter has twice the necessary capacity to serve the condenser so that when the second condenser is installed there will be available three direct-current machines, any two of which will be sufficient to excite the condensers and supply current for all other purposes, leaving the third as a spare. This is another example of the precautions taken to insure continuity of operation at this station.

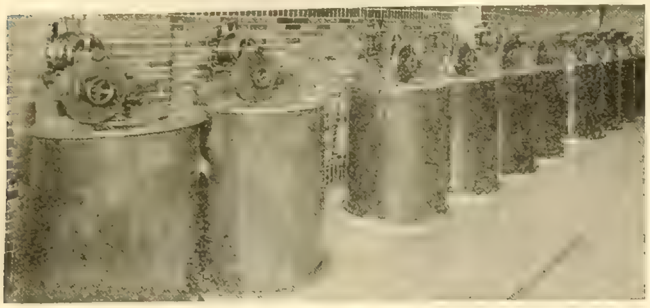


FIG. 9—ROW OF 85 K.V.A., AIR-COOLED AUTOMATIC VOLTAGE INDUCTION REGULATORS

SWITCHBOARD

All apparatus in the station is controlled from the switchboard. This board is semicircular, and the control desk is located at the center of the circle formed by the board, so that all the points on the board are equidistant from the operator. All instruments, control switches, relays and other devices are mounted on the front of the board. In the rear are terminals and switches for testing the relays and instruments. Leads are carried from every voltage transformer in the station to a small panel on the control desk so that readings can be taken on any instrument with a standard voltmeter.

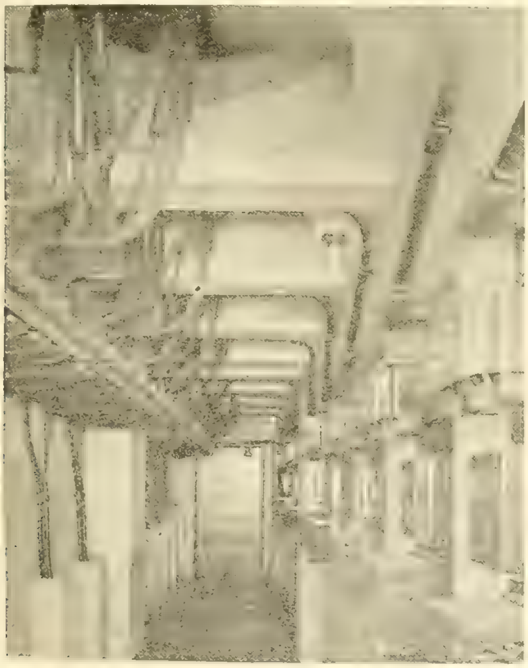


FIG. 10—COMPARTMENT BELOW THE INDUCTION REGULATORS
Showing the connections to the regulators on the left and the primary and secondary induction relays and the line drop compensators on the right.

Each circuit breaker control circuit is fused separately, and all control and instrument wires are carried through the floor to the basement and connected to the control cables through terminal blocks so that every wire is easily accessible. Beginning at the left in Fig. 12 can be seen, the high-tension panels, the graphic meters, the voltage regulator for the synchronous condenser, the outgoing feeder panels with meters, circuit breaker control switches, and relays and at the extreme right the house circuit panel.

FIG. 11—VENTILATING BLOWERS AND THEIR MAGNET SWITCH STARTERS
Air is supplied to the transformers and regulators.

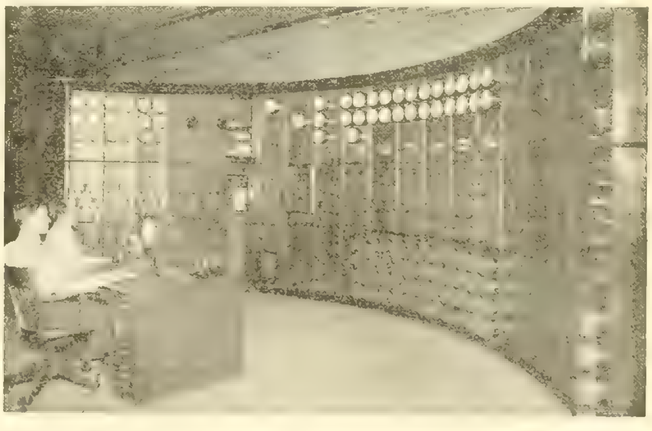


FIG. 12 GENERAL VIEW OF SWITCHBOARD AND CONTROL DESK

RELAYS AND METERS

Each incoming high-tension feeder is protected by a reverse-power relay and an overload relay, which causes the circuit-breaker to open under overloads of definite duration. Relays are also used to cut out the transformers in case of internal trouble and also to protect the outgoing feeders. Each outgoing feeder is provided with a polyphase indicating wattmeter the energy being metered on the secondary side of the transformers.

Turbines and Reduction Gears in the Merchant Marine

J. A. Davies
Engineer, Marine Dept.
Westinghouse Electric & Mfg. Company

SHORTLY AFTER the outbreak of the present war, when the magnitude of the struggle against German militarism became apparent, the allied nations entered the markets of the United States to purchase from our vast resources many of the things which the greatest of all wars had so unexpectedly compelled them to obtain. Contracts were placed for shells and guns, powder, aeroplane parts, shoes, wheat, harness, mules and all of the paraphernalia which modern armies need.

At the outset, the ship tonnage available for transporting this war material was sufficient, but early in 1915 when Great Britian began to move overseas the first of her home and colonial armies, the shipping question became acute. Many of the larger British and French ships trading in the North Atlantic were transformed into troop ships or auxiliary cruisers. Also at about this time the first of the completed material which American firms had contracted to supply began to arrive at the seaboard and all of the available allied vessels were pressed into service to transfer these importtant supplies to Europe. Naturally the Germans had appreciated the danger to themselves of permitting the allies to draw without restraint on this country's great storehouse. Unable to carry out the customary methods of dealing with contraband, as provided by the Hague conventions, Germany invoked the aid of her submarine fleet and instead of seizing merchant vessels loaded with contraband, the ships were torpedoed and sunk.

The consequent loss of tonnage, the risk of destruction, and the volume of material awaiting transportation combined to increase cargo rates, which quickly reached unprecedented figures. Many neutral vessels were attracted to the trade, among the most active of these being Norwegian ships. The demand for new tonnage became insistent, but the old markets for such ships were not available. Great Britian, which in pre-war times had built so many of the so-called tramp, or freight carrying steamers, was utilizing all of her shipbuilding resources to increase her naval strength and thus ensure her supremacy over the German fleet beyond all doubt. Such few yards as France and Italy possessed were fully occupied with domestic needs.

The shipping world outside of Great Britian naturally turned to the United States. Orders for new ships grew in such amazing numbers that the old established shipyards of this country were soon filled to capacity. The need for ships was so great that American capital quickly appreciated the opportunity and new shipbuilding companies were formed. It was very obvious to those in charge of the new yards that the old time methods then in vogue could not be adopted if ships were to be built quickly. The new yards were started to take the fullest financial advantage of the extraordinary market which had increased the price of ships from \$52 to \$100 per ton almost overnight. Consequently it was decided, in almost every instance, that the building of the hulls and the assembling of the machinery should be the extent of the shipyard's activities. The machinery was to be purchased from established manufacturers. This was easily possible with the auxiliary machinery such as pumps, deck winches and steering engines, as such units had long been specialties with various well-known builders. The main propelling machinery was, however, a more difficult problem. For many decades the reciprocating engine had been pre-eminent as the propelling medium of the average tramp steamer. Naturally shipowners were reluctant to depart from such a well-beaten track, but the exigencies of the moment, in which the demand for

FIG. 1—NORWEGIAN STEAMSHIP "MALMANGER"
Equipped with Westinghouse geared turbine propelling machinery and condensing apparatus.

ships was high and the facilities for the production of suitable reciprocating engines were low, compelled the adoption of a new type of propelling unit.

The steam turbine driving the propeller shafting through reduction gears was, of course, the natural choice. Therefore, the new shipyards, and also some of the older yards, turned to builders of such machinery to aid them in the production of the ships. This type of machinery had been designed and built by the late Mr. George Westinghouse as far back as 1909. As a result of his well-known foresight in such matters The Westinghouse Machine Company some years ago became the pioneer in high-powered high-speed turbine and reduction gear transmission. Consequently, they were fully equipped to build successful machinery of this type and were among the first to contract for marine propelling machinery. The designs of the machinery for marine work had already considerable attention and therefore the opportunity thus afforded, by this unprecedented demand for ships, to introduce modern machinery of the most suitable type was quickly recognized.

While it was generally felt that the reciprocating engine would give way to the more economical steam turbine and reduction gear unit for marine propulsion yet, prior to the war, its adoption had been slow. The first contract was for the propelling equipment of two oil tank ships. These were ordinary ten knot, single-screw ships requiring 2500 horse-power, the revolutions of the propeller were 70 per minute. As the power and speed conditions of these vessels were generally suitable for a large number of freight and tank steamers, a standard design of both turbines and reduction gears was prepared.

It was thought that ships having only a single screw should be fitted with two turbines, each driving a pinion meshing with a common gear wheel. The turbines were to be capable of independent operation both ahead and astern so that if one of the turbines or gears broke down at sea, the ship could still make port at a slightly reduced speed by using the other turbine. This plan of double turbine drive naturally suggested the use of the economical compound type, in which the high and low pressure elements are arranged in separate cylinders and both made reversible. The turbines were designed to operate at 3600 r.p.m. at normal speed, this being the best speed for maximum economy with minimum weight.

The reduction from the high speed of the turbines to the low speed of the propellers (a total reduction of 51.5 to 1) was made by the use of double reduction gears, the first gears reducing from 3600 to 450 r.p.m., and the second gears from 450 to 70 r.p.m. The combination thus produced was a typical example of the best arrangement of turbine geared machinery for slow-speed moderate-powered vessels. The double reduction gears with their large ratio permitted the use of the most satisfactory turbine speed and rendered possible the adoption of a large, efficient propeller so well suited to a slow-speed ship.

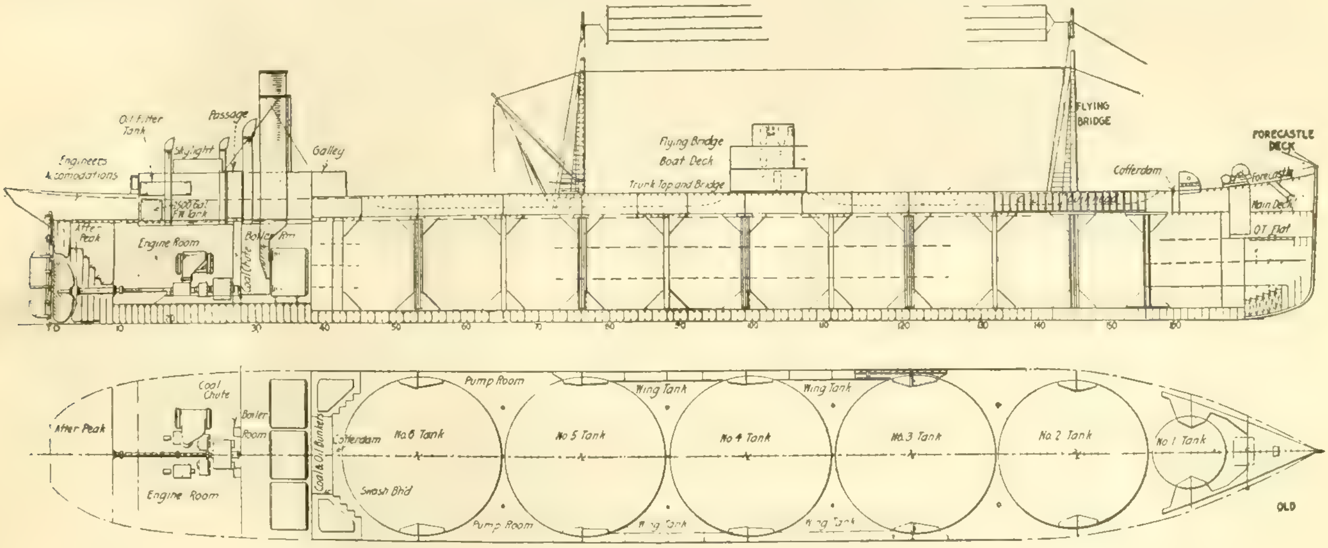


FIG. 2—INBOARD PROFILE AND DECK PLANS
Of the oil tank steamship shown in Fig. 1.

The first set of this machinery was installed in the Norwegian oil tank steamer "Malmanger", shown in Fig. 1. The high-pressure turbine is shown in Fig. 5 and the low-pressure turbine in Fig. 6. The double reduction gears are illustrated in Fig. 4 and a view looking forward in the engine room is given in Fig. 3. The high-pressure turbine can be seen in the foreground, on the right or starboard side, the low-pressure turbine and condenser being on the port side, the propeller shafting passing between the two turbines. The plan view of the ship, Fig. 2, gives a graphic idea of the smallness of the driving turbines in comparison with the size of the vessel. Unfortunately the "Malmanger" was sunk by a mine on her maiden voyage, going down off the Irish coast on March 22, 1917. Her sister ship, the Norwegian vessel "Golaa", was fitted with the next set of machinery and is still afloat. This latter vessel has made three round trips between the

United States and Europe and is at present engaged in coastwise trade.

The demand for machinery increased so rapidly that The Westinghouse Machine Company quickly ob-

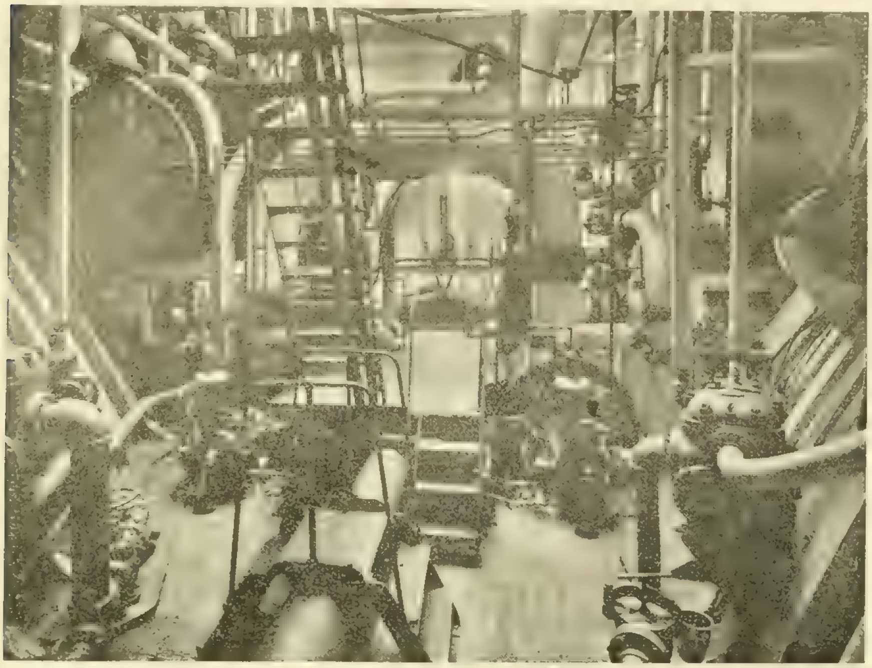


FIG. 3—ENGINE ROOM OF THE STEAMER

tained contracts for several sets. The ships ordered prior to January 1, 1917 which have been placed in service are listed in Table I.

TABLE I STEAM TURBINE DRIVEN SHIPS IN SERVICE

Name of Ship	Built at	Type of Ship	Shaft Horse Power	R. P. M.	
				Turbines	Propeller
Malmanger	Chester, Pa.	Oil Tank	2900	3600	70
Golaa	Chester, Pa.	Oil Tank	2900	3600	70
Hisko	Chester, Pa.	Oil Tank	2900	3600	70
Avondale	Chester, Pa.	Oil Tank	2900	3600	70
Sudbury	Chester, Pa.	Freight	2300	3600	72
Overbrook	Chester, Pa.	Oil Tank	2900	3600	70
Coronado	Oakland, Cal.	Freight	2400	3600	90
Yosemite	Oakland, Cal.	Freight	2400	3600	90
Yellowstone	Oakland, Cal.	Freight	2400	3600	90
Oakland	Oakland, Cal.	Freight	2900	3600	90
Westerly	Seattle, Wash.	Freight	2500	3600	90
Westwood	Seattle, Wash.	Freight	2500	3600	90
West Eagle	Seattle, Wash.	Freight	2500	3600	90
Maui	San Francisco	Passenger and Freight	12500	2000	120
West Ford	Seattle, Wash.	Freight	2500	3600	100
Polar Sea	Baltimore, Md	Freight	1800	3600	90
Accomac	Los Angeles,	Freight	3000	3600	100
Wakulla	Los Angeles,	Freight	3000	3600	100

Of these ships two have been lost. The "Malmanger," as previously explained, and the "Westerly", which was sunk in collision off the coast of France April 29, 1918. It is to be hoped the other ships will fare more fortunately, as to date the machinery performance of all of them has been most satisfactory. The following extracts are from reports received:—

REPORT OF ENGINEER ON S. S. "HISKO" CONCERNING VOYAGE FROM A U. S. ATLANTIC PORT TO ENGLAND.

"On the voyage over, the weather was very rough and the governors were in action much of the time and worked perfectly. The other ships had to slow down. Their engines were racing too badly.

On Feb. 8th it was so rough that the convoy had to heave to for about ten hours. We got out of touch with the other ships and went on alone and arrived three days ahead of any of the ships of our convoy.

Two of the ships in our convoy had foundered on the day we hove to and all hands were lost. All we lost were two life rafts and the starboard life boat on the bridge was smashed in.

I examined the gears upon arrival and they showed no signs of wear."

On arriving at a U. S. port the captain of the "Hisko" confirmed the engineer's statements in a report to the Navy Department.

REPORT OF ENGINEER ON S. S. "WESTERLY" CONCERNING VOYAGE FROM A PACIFIC TO AN ATLANTIC PORT VIA THE PANAMA CANAL.

"Sailed for Panama Canal February 27th, 7:00 a.m. Adjusted compass and was all clear for sea at 10:45 a.m. Struck a few days of choppy sea. Made no stops until arrived at Panama, 3-17-18, 2:35 p.m.

3-21-18—3:15 p.m. lifted anchor for the United States. Had fair weather during entire voyage with the exception of about three days.

Machinery performed O. K. Gear oil pumps handle oil nicely. All pipe work and fitting done by shipyard on turbines and gears was good. Experienced no trouble whatever with oil leaks.

The S. S. Westerly made quite a record. On arriving at Balboa, we took no water aboard and no repairs whatever required. So far no Shipping Board boat, which had already passed through the Canal, went straight through without in need of some repairs.

The voyage was a pleasant one for all aboard. The crew, especially in the engine room, seem to like the installation. The chief engineer speaks well of the machinery and its performance.

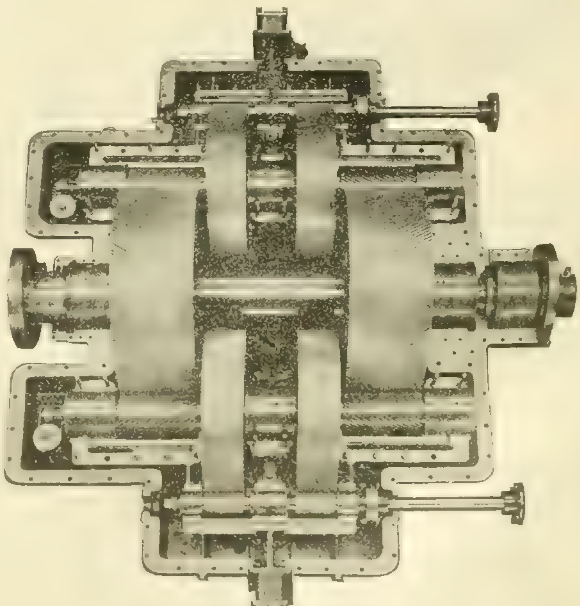


FIG. 4—DOUBLE REDUCTION GEARS

Arrived off Cape Henry 7:05 p.m. March 29th. Dropped anchor and remained there until 12:20 noon of the 30th, then got underway for Newport News, Va., and arrived there 3:53 p.m. of the 30th.

Made thorough inspection of all reduction gears and oil sprays at Colon and Newport News. Everything looked good."

The ships listed in Table I are but the beginning of a large fleet to be fitted with Westinghouse machinery. Equipments are now built or on order for 300 single-screw vessels, all of which are for the Emergency Fleet Corporation. Both the East Pittsburgh and Essington works are busily engaged in this most important war work. Not only are turbines and reduction gears for propelling the ships being built but the major portion of the auxiliary equipment such as condensers, both main and auxiliary, circulating pumps

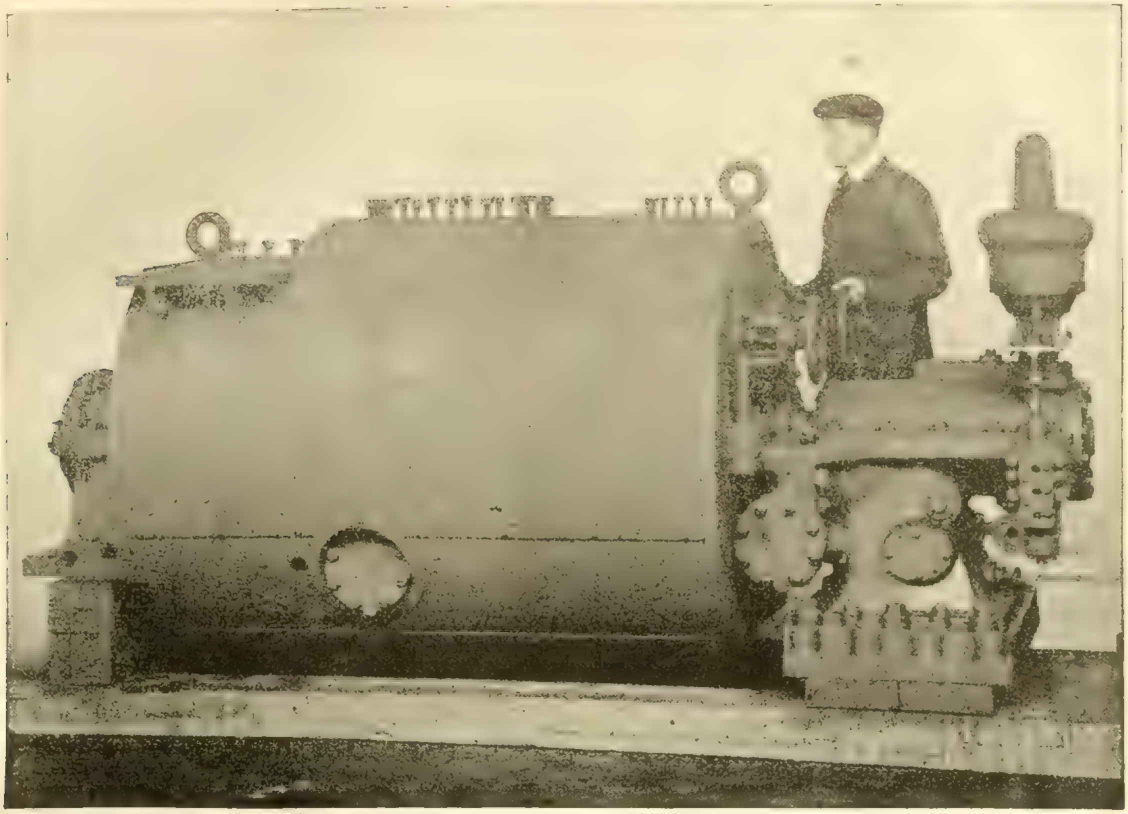


FIG. 5—HIGH-PRESSURE TURBINE

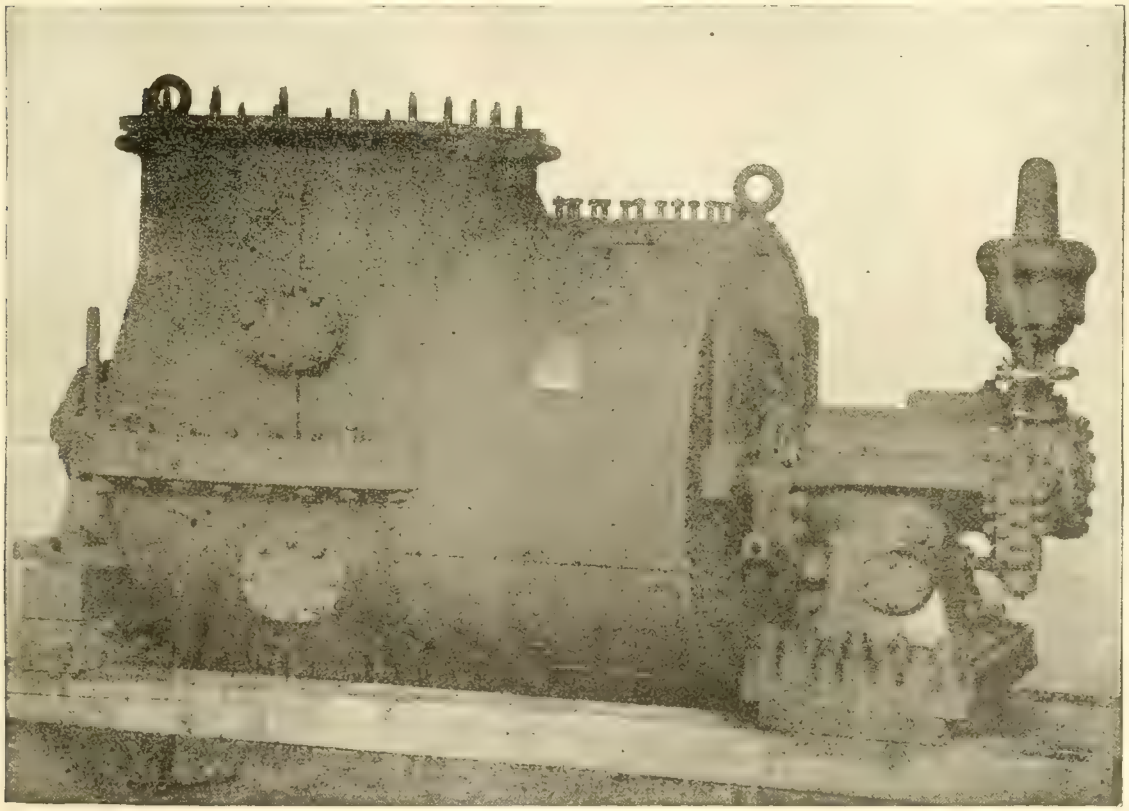


FIG. 6—LOW-PRESSURE TURBINE

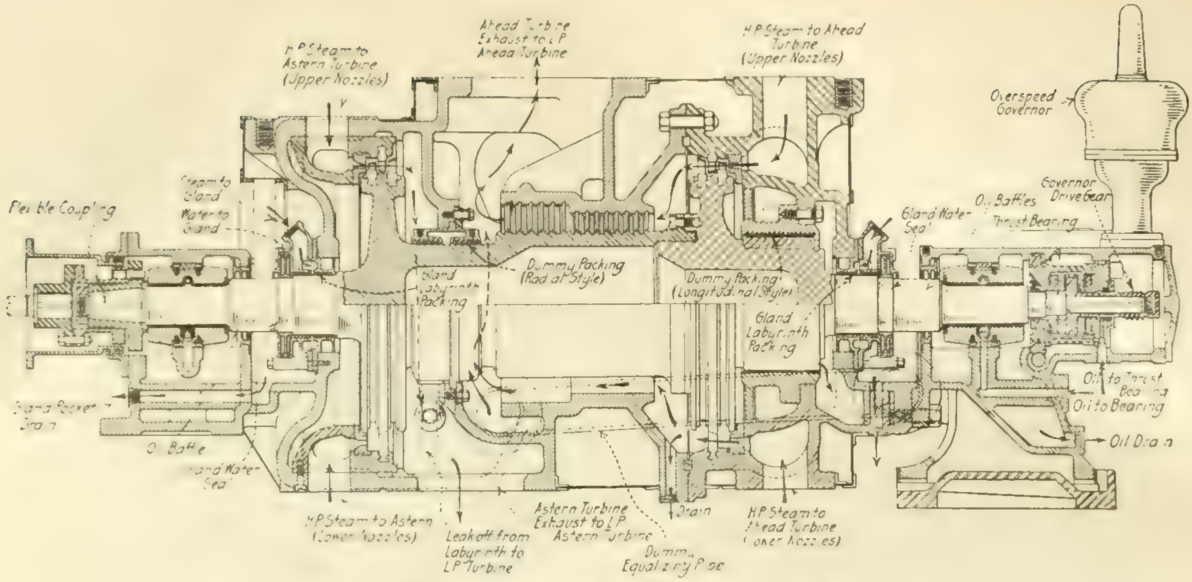


FIG. 7—CROSS-SECTION OF HIGH-PRESSURE TURBINE

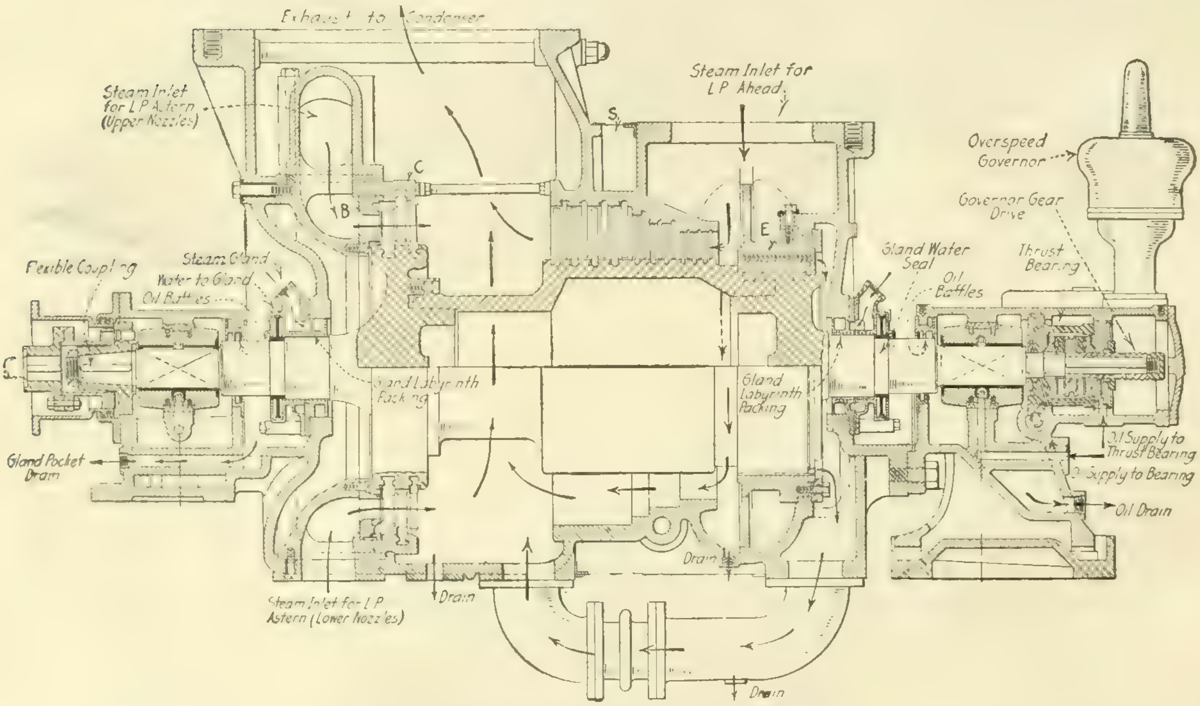


FIG. 8—CROSS-SECTION OF LOW-PRESSURE TURBINE

with geared turbine drives, vacuum apparatus, generating sets, and lubricating pumps and fittings are also being supplied. The maneuvering valves for handling the main turbines with promptness are also no small part of the program. Much depends on the ease with which rotation can be changed from ahead to astern when the ship is being docked. A section of this valve is shown in Fig. 9. Adjoining the maneuvering valve in Fig. 9 is an additional double-seated governor valve, the action of which is so highly commended in the report from the engineer on the "Hisko". Its purpose is to control the speed of the turbine should the load be dropped suddenly, as would occur should the propeller become uncovered when the ship pitches in a heavy sea.

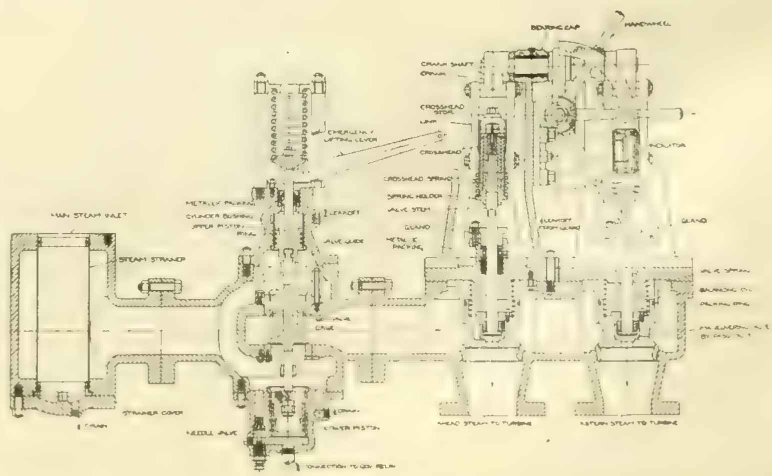


FIG. 9—SECTION THROUGH STEAM STRAINER, GOVERNOR AND MANEUVERING VALVES

From the foregoing it will be realized that the part this Company is taking in the war work of the United States is of a very important character. Ships are among the most pressing needs of the government. Obviously the propelling machinery of such vessels must be absolutely reliable so that important schedules of ship movements can be met without fail. To this end the Company is working and they have reason to believe that the apparatus now being built will fully uphold the reputation for efficiency and reliability which their land machinery already enjoys.

The Representation of Alternating-Current Quantities by Vectors

Alexander D. DuBois

The alternating-current generator, reduced to its simplest form, may be considered as a single coil of wire caused to rotate with uniform angular velocity in a uniform magnetic field, about an axis in a plane perpendicular to the magnetic field. Such a coil, *aa'* in Fig. 1, if rotated counter clockwise about *O*, will be threaded by the maximum number of lines of force when the plane of the coil is at right angles with the magnetic flux, that is, with the angle $\theta = 0$. At this instant, the motion of the conductors is parallel to the flux. No lines of magnetic force are being cut by the conductors and therefore no e.m.f. is induced. When the coil has reached the position shown in Fig. 1, it is cutting obliquely through the lines and an e.m.f. is generated in proportion to the rate of cutting. The rate of cutting, is a maximum when θ becomes 90 degrees since the conductors are then moving at right angles to the flux. As the rotation of the coil continues, the rate of cutting, and hence the induced e.m.f., decreases until, when the coil is again horizontal ($\theta = 180$ degrees the e.m.f. is again zero. At this point the e.m.f. is evidently reversed, for the conductor *a* which has been cutting lines of force from right to left during the first half revolution is now beginning to cut the same field of force from left to right. During the second half-revolution, then, the e.m.f. grows and decreases again to zero in the way explained for the first half-revolution, but in the opposite direction with reference to the wire.

During one revolution of this ideal armature, the e.m.f. has passed through a cycle of values, increasing first in one direction, then in the other. During each succeeding revolution, the cycle is repeated, and the result is an alternating e.m.f., or difference of potential between the two slip-rings to which the terminals of the coil are connected.

It remains to determine the mathematical law by which the instantaneous value of e.m.f. may be expressed for any position of the rotating coil. It is evident that it is the horizontal component of the peripheral velocity of the conductor *a*, Fig. 1, which determines the rate of cutting of the magnetic lines. Let the peripheral velocity V_0 of *a* be represented by the length of the line *ac*. Its direction at any instant is represented by the same line since *ac* is drawn perpendicular to the radius *Oa*. Now if the velocity V_0 be resolved into horizontal and vertical components V_1 and V_2, it is the component V_1 which determines the electromotive force at any moment, for the vertical component is parallel to the flux and is not effective in generating e.m.f. In other words, if the conductor moves horizontally with a variable velocity V_1 instead of with a constant velocity V_0 the same lines of force would be cut per unit of time.

Since angle *bac* is equal to angle θ, by construction, (their sides being respectively perpendicular), it is evident that

$$\frac{bc}{ac} = \sin\theta = \frac{V_1}{V_0} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\text{hence } V_1 = V_0 \sin\theta \qquad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

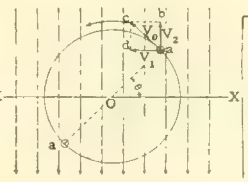


FIG. 1—ACTION OF AN ELEMENTARY COIL IN A UNIFORM FIELD

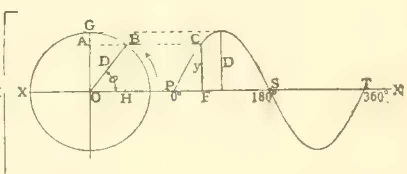


FIG. 2—CLOCK DIAGRAM AND DEVELOPED SINE WAVE
Of the electromotive force generated by the coil, Fig. 1.

The instantaneous value of electromotive force *e* is proportional to V_1. Hence, *e* is proportional to the sine of the angle θ. When $\theta = 0$, $e = 0$, and when $\theta = 90$ degrees, *e* is a maximum. Since V_0 is equal to the maximum value of V_1, equation (2) may be written in the form;—

$$V_1 = (V_{1\,\max.}) \sin\theta.$$

and since *e* is directly proportional to V_1

$$e = e_{\max.} \sin\theta.$$

The electromotive force produced by the alternator is therefore a function of the sine of the angle θ. If plotted to rectangular co-ordinates, using values of θ as abscissae, and the corresponding instantaneous values of e.m.f. as ordinates, a sine curve is the result. For values of θ between 0 and 180 degrees, sine θ is positive; for values between 180 and 360 degrees it is negative; so the sine curve alternates above and below the *X* axis as shown in Fig. 2, where the maximum

e.m.f. is represented by the ordinate D, while the instantaneous value corresponding to any angle indicated by the abscissa PF will be represented by its corresponding ordinate y.

Since the angular velocity of the conductors is uniform, the angles passed over are proportional to time, and if desired time may be substituted in place of angles as abscissæ, in plotting the sine curve. In either form the sine curve shows graphically how the e.m.f. changes from moment to moment, with each increment of time or of space traversed by the conductors. The same graphical representation will evidently apply to a current, a magnetic flux, or any alternating quantity which is known to conform to the sine law in passing through its cycles of changing values.

A purely ideal case has been considered; uniform magnetic field, uniform speed, no iron in the rotating coil. In commercial generators these conditions do not obtain. The wave forms which occur are usually not true sine curves. But the error thus introduced is commonly negligible for practical purposes; and if not, the irregular wave form can be reduced to an equivalent sine wave, which may be represented vectorially.

THE SUBSTITUTION OF VECTORS FOR SINE CURVES

Were it necessary to plot sine curves for the graphical solution of alternating-current problems, the process would be cumbersome. Fortunately such a procedure is needless, since any system of sine curves, provided they are all of the same frequency, may be replaced by simple vectors. Referring to Fig. 2, let C be any point on a sine curve and let D be its amplitude or maximum ordinate. Then by the definition of the curve, any ordinate, CF is equal to $D \sin \theta$, where θ is represented in rectangular co-ordinates by the abscissa PF. With the point O as a center and a radius OB equal to D, a circle representing the path of the revolving point B is drawn. The radius vector of the point B is the line OB. If the line OB be drawn at any angle θ with the horizontal axis;—

$$OA = HB = OB \sin \theta.$$

or, expressed in words, the projection OA of the radius vector OB upon the vertical axis is at all times equal to $OB \sin \theta$. But OB equals in length D the maximum ordinate of the curve; therefore $OA = D \sin \theta$. This is the equation of the sine curve. Any point of the sine wave is completely defined if its two coordinates are known. The abscissa is given by the angle, θ, which the radius vector makes with the horizontal line of reference; the ordinate is given by the projection OA of the radius vector upon the vertical axis. Any sine curve is therefore completely represented by a radius vector whose length represents, to some scale, the maximum ordinate of the sine wave. It is not necessary to draw the vector in particular position, that is, at any prescribed angle with the X axis, for it must be considered as being successively in all positions, in order to represent completely a full cycle of the sine curve.

If two sine wave electromotive forces in a series circuit are out of phase, they may be represented by sine curves which do not reach their maximum points simultaneously. Thus the curves A and B, Fig. 3, may represent two such electromotive forces. Each of these curves is independently known if its maximum ordinate is known. Thus the curve A may be represented by a vector Oa; the curve B by a vector Ob and each will adequately represent its respective sine curve regardless of the position or direction in which it is drawn.

But to represent the phase relation of the two curves, the vectors must be drawn in the same phase relation as the curves and must be considered as rotating together. For example, if the curve B passes through zero sixty degrees later than curve A, the vector Ob must be drawn so that its projection will be equal to zero, sixty degrees later than the projection of the vector Oa. This condition is assured by drawing the two vectors at an angle of 60 degrees with each other; for a vector's projection is zero only when the vector is coincident with the X axis, and if the vectors are 60 degrees apart in angular displacement and are rotated together as though they formed a rotatable framework pivoted at O, it is evident that the vector Ob will reach the X axis 60 degrees later than the vector Oa.

Having established a vectorial scheme for representing two sine curves which are of equal frequency

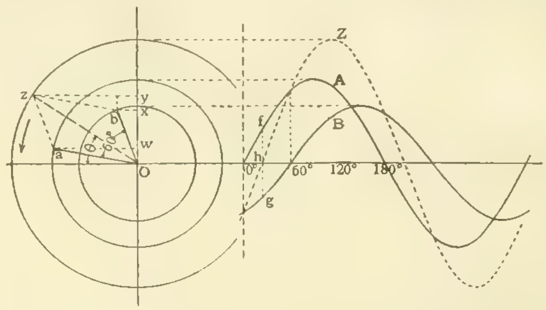


FIG. 3—SUMMATION OF OUT-OF-PHASE SINE WAVES

but of any angular displacement and any relative amplitudes, the representation of their resultant can be studied. If the curves A and B represent two electromotive forces, generated, for example, by two armature coils connected in series but mechanically displaced, their combined action must be such as could be represented by a single, resultant sine curve whose every instantaneous value is equal to the algebraic sum of the corresponding instantaneous values of the two component curves. By combining the ordinates of curves A and B the resultant curve Z, Fig. 3, is obtained. To draw a vector which will represent the resultant sine curve Z both in amplitude and phase relation, assume only the two vectors Oa and Ob are given. It may be arbitrarily stated that the line Oz obtained by constructing the parallelogram $zaOb$ is the resultant radius vector desired. The geometrical construction is the same as that employed in the composition of forces and velocities in analytical mechanics. It is not self-evident, however that the diagonal of a parallelogram thus constructed will fulfill the requirements of the present case.

To demonstrate the correctness of this construction, it must first be shown that the line Oz is correct in phase relation; and second that it is of the proper

length. Referring to the sine curves the resultant curve Z must have such a phase relation with the component curves as will cause its instantaneous value to be zero when the corresponding instantaneous values of the curves A and B are equal and opposite; that is Z must pass through zero at a point h where $fh = hg$. This means that when the projections of vectors Oa and Ob are respectively positive and negative and of equal magnitude, the projection of the resultant vector must be zero. In Fig. 4, the vector Oz and its parallelogram are reproduced with the line Oz coincident with the X axis when its projection on the Y axis is zero. Since the diagonal of a parallelogram divides it into two like triangles the altitude na of the triangle zOa is equal to the altitude bj of triangle zOb. But $na = Of$ and $jb = gO$. The projections of the two component vectors are therefore equal and opposite when the projection of the resultant is zero. Thus the phase relation of the vector Oz is correct when drawn as above described.

With Oz drawn in the proper phase relation, its length is evidently correct if its projection is always equal to the algebraic sum of the projections of the component vectors. Refering back to Fig. 3, it is evident that

$$Oy = Ox + xy$$

but

$$xy = Ow$$

since, by construction, az is equal and parallel to Ob. Hence;—$Oy = Ow + Ox$, or expressed in words, the

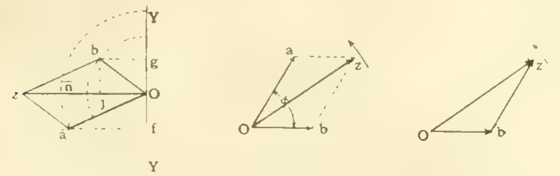


FIG. 4 FIG. 5 FIG. 6

FIGS. 4 TO 6—VECTOR RELATIONS OF E.M.F.'S OF FIG. 3

projection of Oz on the Y axis is equal to the sum of the projections of Oa and Ob.

It is now proven that the combination of radii vectors may be carried out by the construction of parallelograms, in the same manner as the composition of forces, and that the resultant vector thus obtained will faithfully represent the resultant sine curve, both in amplitude and phase relation. Having established these facts, it is unnecessary to retain the sine curves themselves or even the circles or axes of reference, in connection with the vectors. The parallelogram $zaOb$ may be removed entirely from the circular diagram and placed in any convenient position, as in Fig. 5. The relations are still faithfully portrayed, provided the lengths of the vectors and the angles between them are correctly drawn; but it is necessary to keep in mind the direction of rotation of the diagram in order to know which quantities are leading and which are lagging in phase. The arrow showing direction of rotation should therefore be retained.*

*Counter clockwise rotation of vectors was adopted as standard by the International Electrotechnical Commission at Turin in 1911; is recommended in the A.I.E.E. Standardization Rules and may generally be assumed where no direction is specified.

As a still further simplification, the triangle as shown in Fig. 6 may be substituted for the parallelogram. The resultant Oz obtained from the triangle is manifestly the same as that derived from the parallelogram, both in its length and phase relation; but it is now necessary, in order to avoid confusion, to place arrow-heads on the vectors themselves. It is customary to place the arrow-head on the free end of each vector to indicate that it is this end which describes the circle when the diagram is rotated, the unmarked end being the pivot or center of rotation. When the arrow-heads have been thus placed, all pointing away from the center of rotation in Fig. 5, any of these vectors may be transposed to other positions, as in Fig. 6, provided they are kept always parallel to their original directions and are not turned end for end. Turning a vector end for end, with relation to the remainder of the diagram, is obviously equivalent to changing its phase relation by 180 degrees. For example, Figs. 7, 8 and 9 show voltage relations in a three-phase circuit. In each of these figures the upper diagram shows the triangular combination of the vectors, whose true phase relations are shown by the lower diagrams. Fig. 7 represents the normal relations. The arrow-heads all follow around the triangle in the same direction, indicating proper angular displacement of the phases as shown by the

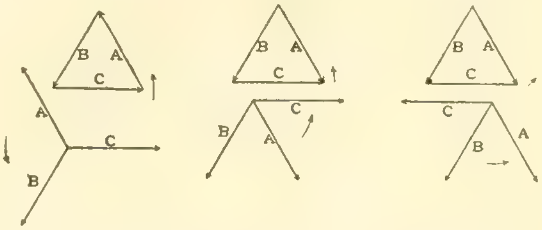


FIG. 7 FIG. 8 FIG. 9

FIGS. 7 TO 9—VOLTAGE RELATIONS IN A THREE-PHASE CIRCUIT

lower diagram of the same figure. Reversing vector A by transferring the arrow-head to its opposite end, produces the conditions shown by Fig. 8, in which the result, made clear by the lower diagram, is a reversal of phase A of the circuit. Fig. 9 shows the result of reversing phases A and C while keeping phase B unchanged. It should be clear from these considerations that, while vector arrow-heads may be omitted from the completely and correctly assembled diagram, it is quite essential to make use of them when employing the simpler but more artificial method of triangles. And, it is evidently as necessary as before to keep in mind the direction of rotation of the figure.

Since the vector which represents a sine wave must be equal in length to the maximum ordinate of the wave, while ammeters and voltmeters measure effective values, it is evident that if full-length vectors are employed, a constant must be applied to reduce the one value to the other. The effective value is 0.707 times the maximum value. In practice it would be rather a cumbersome process to find the true length of each vector by dividing each instrument reading by this constant, and then reduce the results back to effective values by multiplying the resultant vectors by the same

constant. And such a procedure is unnecessary since the working vectors are in effect multiplied by the same constant by simply reducing their lengths so that they represent, to the same scale, the effective values of the quantities in the problem. The results are then scaled directly from the graphical diagram in terms of effective values. Thus, the vectors that are commonly employed in practice are not the true, full-length vectors of the foregoing discussion: they are rather the stubs that remain when the outer ends of the spokes have been cut off. These might be called effective vectors; and no confusion can arise as to how they originated if such a name is applied to them.

Consideration of Fig. 10 will show that such treatment is permissible, because it does not alter the relative lengths of the several vectors of a diagram, and does not affect their phase relations. The lines *oa*, *ob* and *oc* are the truncated vectors, representing effective

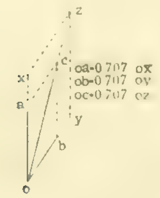


FIG. 10—RELATION OF MAXIMUM AND EFFECTIVE VECTORS

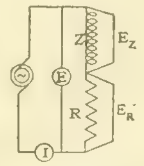


FIG. 11—THREE-VOLTMETER METHOD OF MEASURING POWER

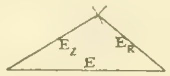


FIG. 12—VECTOR TRIANGLE OF VOLTAGES OBTAINED IN FIG. 11

values, and the construction used in a practical problem. The extended lines *ox*, *oy* and *oz* are the true vectors. The dotted extensions *ax by* and *cz* are the portions omitted from the working diagram, and retained only in the imagination of the worker, that he may not lose sight of the logic of the method.

These fundamentals of vector representation may be illustrated by a practical example. The three-voltmeter method of measuring power illustrates an application of the triangular combination of vectors, and the importance of not losing sight of the arrow-heads. Thus to measure the power input of an inductive load *Z*, Fig. 11, connected in series with a non-inductive resistance *R*, the three voltmeter readings E, E_z, and E_R, represented in Fig. 12 to a convenient scale by three straight lines, are combined to form a triangle. Although the angles are all unknown the triangle is completely determined by its three sides, and is constructed by striking arcs with the radii E_R and E_z, having their centers at the ends of the third side E. This triangle however, tells nothing without a correct interpretation of its angles. The formula for the power input of Z, is

$$P_z = E_z I \cos\theta$$

The angle θ must therefore be determined. It is known to be the angle of phase displacement between the voltage E_z at the terminals of load Z and the current I of that load. In order to determine this angle it is necessary to have clearly in mind a vector diagram of the general construction of Fig. 5, with its rotation properly indicated. It is known that I is in phase with E_R, that E_z is leading in phase with respect to I (since Z is an inductive load), and that E, the total voltage, must be the resultant or vector-sum of E_R and E_z. This

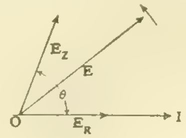


FIG. 13

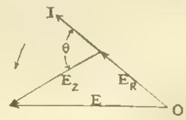


FIG. 14

FIGS. 13 AND 14—VECTOR RELATIONS OF VOLTAGES OF FIG. 11

knowledge of the conditions gives a mental picture such as Fig. 13, in which the desired angle θ is the angle by which E_R lags behind E_z. And this mental picture enables one to place the arrow-heads on the vectors of Fig. 12, thus locating the angle θ and determining its numerical value. The result is shown in Fig. 14, in which θ is seen to be an external angle of the triangle.

It is in this form that vectors are commonly employed, their lengths representing effective values, and the angles of their triangular combinations, properly interpreted, representing the phase relation. The method is applicable to any quantities which vary in accordance with the sine law, the only additional restriction being that the quantities treated in a given diagram must all have the same frequency.

Electric Propelling Machinery

For the U. S. Battleship "TENNESSEE"

WILFRED SYKES
General Engineer
Westinghouse Electric & Mfg. Co.

THE DEVELOPMENT of the propulsive machinery for capital ships during the last few years, has been very rapid. The reciprocating engine, which has held the field until recently, had been developed in the United States Navy to a high degree, but the obvious advantages of rotating machinery led to its being superseded by the direct-connected steam turbine. The direct turbine drive left a good deal to be desired from the standpoint of economy, especially at light loads, which is of particular importance as a battleship steams most of the time at cruising speed which requires only a small percentage of the power at full speed. The economy at cruising speed has been considerably improved by the addition of geared cruising turbines connected to the main turbines through a suitable clutch when running at cruising speeds.

A number of years ago the United States Navy determined to experiment with two new types of drive that seemed promising, but which had not been given practical tests, and two of the large colliers were equipped, one with geared turbines and the other one with electric propulsion. Both of these equipments have given satisfactory service and have shown that either arrangement would be feasible for battleship propulsion. In the meantime gearing had been developed very extensively for land installations and where the problem is simply to reduce the speed of a high-speed turbine to the propeller speed, the geared drive has proven entirely satisfactory. By the use of a high-speed turbine with geared drive the weight may be reduced very materially and very good economies may be obtained, as the turbine is operated at speeds for which it is naturally best adapted. By the addition of a cruising turbine for lower speeds the water rate may be maintained practically constant over a large range. The tests made by the Navy Department together with experience gathered from outside sources led to the adoption of geared drive for the 90 000 hp scout cruisers.

The electrically driven collier has also given very satisfactory service, and the ease with which the ship can be maneuvered is very noticeable. The steam consumption of the geared and electrically driven colliers is approximately the same.

After due consideration of the results of various trials, it was decided that electric propulsion would be used for the newer battleships, and a contract was let for the equipment for battleship No. 40, the *New Mexico,* which has recently gone into commission. The well known advantage of electric drive, allowing of the disposition of the apparatus in the best locations, is of the greatest importance in the design of fighting ships. The full advantages of electric drive were not utilized in the case of the *New Mexico* but as the detailed design of the equipment developed, they became obvious and when the contracts for the *Tennessee* and *California* were made, it was realized that the adoption of electric drive revolutionized the design of the ship, and that some of the features of this type of drive which were considered of so much importance when the decision was originally made, were actually secondary compared with the military advantages that were obtained by the utilization of the characteristics of the electric machinery.

In general it may be stated that the electric drive and the gear drive show approximately the same overall steam consumptions, both of which are very much superior to the older systems, so that a decision made

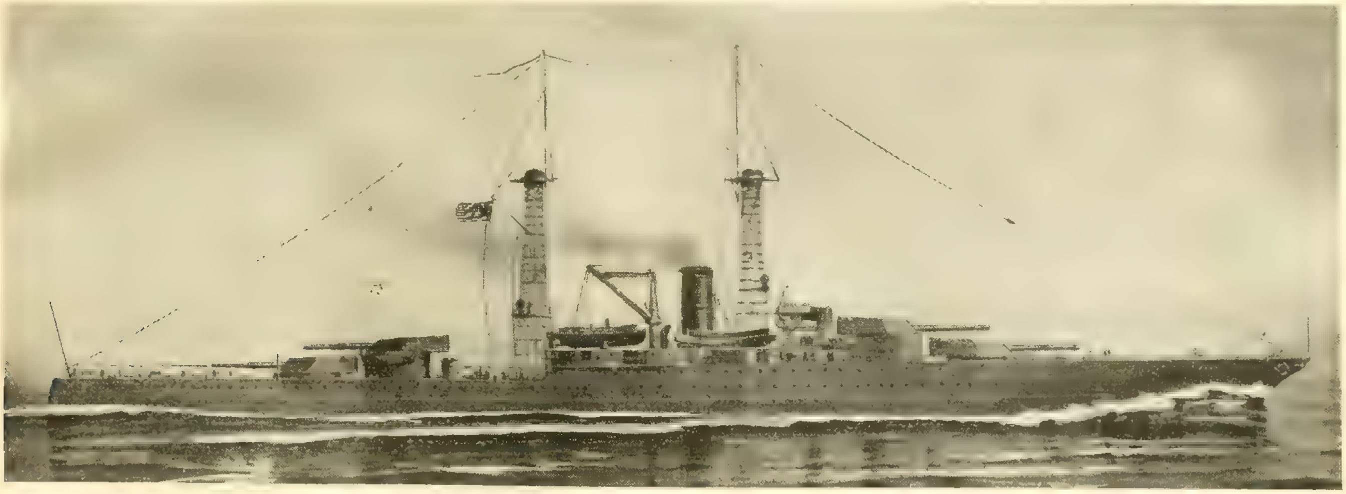


FIG. 1 A MODERN UNITED STATES ELECTRICALLY-PROPELLED BATTLESHIP

on the basis of military advantages to use either one, does not entail any sacrifice in economy. The electric drive has provided a new tool for the naval constructor of great value when designing ships for modern conditions. The question of reliability of electric drive has not been seriously raised, as it was realized that in our central stations, steel mills and other large industries, the same units had already been utilized of equivalent power to those which it was proposed to install in the ship, and the only new condition was that the machinery would be in a ship instead of on dry land.

The *Tennessee* will be one of the most powerful fighting ships built, having displacement of over 32 000 tons, and a speed of 21 knots at full power. The equipment for propelling the ship will consist of four 3-phase induction motors, each driving one propeller, and two turbogenerators for supplying the motors with power. Each of the four motors will develop 7000 hp at a speed of about 180 r.p.m. and will be capable of working continuously at 8375 hp as an overload condition. The motors have two windings, of 24 and 36 poles, so that they have two normal speeds of 123 and 180 r.p.m. with full speed of the turbine. In this way it is possible to run the turbine at its most economical speed when steaming either at full power or cruising at 15 knots. Intermediate speeds are obtained by varying the speed of the turbine and the equipment is designed to maintain a low water rate over the full range of speed from ten knots up. When operating below 17 knots, only one generator is used, and this improves the economy, as the load on the unit is brought nearer to its full capacity. The turbogenerators supplying power to the main units each develop 13 500 k.v.a. at full speed and are capable of carrying 15 000 k.v.a. continuously for the overload condition. The generators are two-pole machines and the unit runs at 2190 revolutions, corresponding to 36.5 cycles per second, with the motors running at 180 r.p.m. The maximum speed of the turbogenerator is 2270 r.p.m., corresponding to 37.9 cycles, equivalent to a motor speed of 186.5 r.p.m. which requires 8375 hp. To obtain lower speeds, the turbine speed is reduced to about 1500 r.p.m. which corresponds to the change-over point from the 24 to the 36 pole connection of the motors. With the change-over of the motor connections, the speed of the generator is increased to 2270 revolutions, corresponding to 15 knots with the 36 pole connection. The motor speed combination is simply the equivalent of a variable ratio of gearing which in the case of the 24 pole connection is 12:1 and with the 36 pole connection 18:1. The direction of rotation of the machines is controlled by reversing switches which simply transpose two of the phases at the motors, the generator of course continuing to run in the same direction. The motors have two separate windings on the stator, one the 24 pole and the other the 36 pole connection. The same results might have been obtained by use of one winding, but this would have entailed greater complication in the connections and would have restricted the design in other ways. The rotor has a single polar winding for 24 poles which is connected to the slip rings in the ordinary way, so that resistance can be inserted in the circuit during starting or reversing. When the machine is operating on the 36 pole connection, the rotor winding cross-connections act as short-circuiting connections for this pole combination. With the 24 pole combination, they act as equalizing connections between points of equal potential. On the 36 pole connection, the motor operates as a squirrel-cage machine and it is not intended that this winding should be used during the starting or reversing, but only as a running winding. In this way, only one winding is used and one set of slip rings.

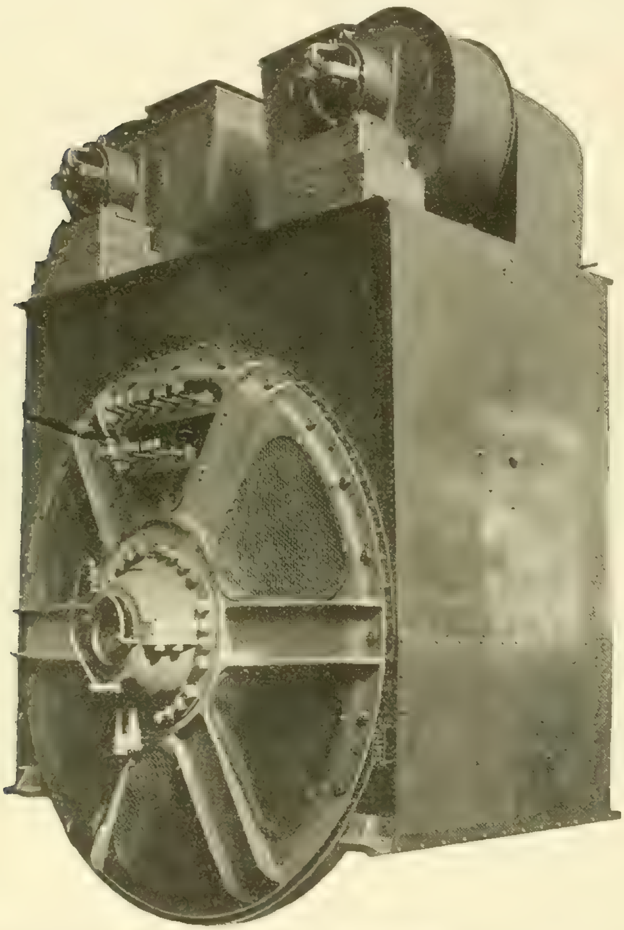


FIG. 2 ONE OF THE MAIN PROPELLING MOTORS OF THE U. S. S. "TENNESSEE"

Showing the ventilating fans mounted on the housing.

The speed of the turbine is varied by means of a unique hydraulically-operated governor. The loading of the governor is regulated by means of a variable pressure oil system, the pressure of which is regulated with great accuracy by a pressure regulating mechanism operated by the control handle. In this way, any mechanical connection through shafts or rods with the governor from the operating point, with the consequent danger of jamming where passing through bulkheads, is avoided. A unique feature of this arrangement is that the pressure is caused to pulsate slightly so that the whole of the regulating and governor mechanism is kept slightly in motion, and thereby prevented from sticking, thereby adding greatly to the sensitivity of the

control, which is of great importance when ships are steaming in formation. The turbines are of the Westinghouse semi-double flow, impulse-reaction type. The high-pressure steam is expanded in suitable nozzles and passes through a two row impulse wheel, after which it passes through the first stage of the reaction expansion, which is single flow. The steam then divides and passes through the low-pressure stages of the turbine, which are double flow. The turbine is provided with an automatic stop to cut off steam in case the speed should exceed the maximum safe-operating value. The main hydraulically-operated governor maintains speed practically constant at any value set by the control mechanism, independent of the load, so that in case the propellers should leave the water during rough weather there will be no racing.

The generators and motors are very carefully insulated for this service so as to prevent damage due to moisture or the accumulation of salt, and also due to the high temperatures which are liable to be encountered in this service. The principal material used for insulation of coils in the slots is mica, and the machines are capable of withstanding slot temperatures up to at least 150 degrees C. without injury. Ventilation of the

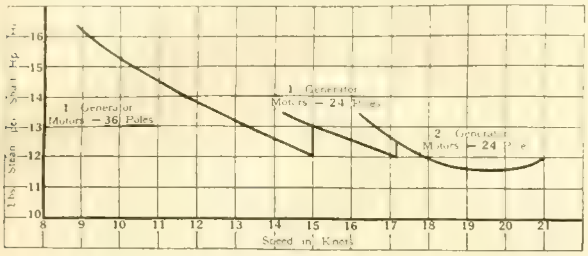


FIG. 3—STEAM CONSUMPTION CURVE

For the propelling machinery of the "Tennessee" including power required for excitation, the main circulating pumps, condensate pumps and motor ventilation.

generators is provided by fans supplying air to each engine room and the fans on the generator forcing the air through the machine and out through ducts. The motors each have two fans mounted directly above them which draw the air through the motor and force it out through the ventilating ducts. The generators are excited from the direct-current power circuit of the ship through boosters which are capable of raising the normal 240 volt supply to 320 volts or reducing it to zero.

The power supply from the turbogenerators is brought to a centrally located control room in which is mounted all the necessary switching apparatus for controlling and distributing the power to the motors. In this room is mounted the regulating apparatus for the main turbines, the field switch and rheostat for the turbogenerator excitation, and the liquid rheostats for the main motors. All necessary instruments for the operation of the equipment are mounted directly in front of the operators and full advantage is taken of the great facility with which electric power can be measured, inasmuch as it will assist in the operation of the ship. For starting and reversing the main motors, automatic liquid rheostats are used which are of a similar design to those used previously for industrial purposes. These liquid rheostats consist of two tanks, the upper containing a series of fixed electrodes and the lower acting as a reservoir. By means of a suitable pump, the electrolyte is caused to flow from the lower to the upper tank at the proper rate to cause the desired acceleration. When the bypass between the two tanks is open, the electrolyte is maintained within the electrode tank at the proper level to give the maximum resistance. When this bypass is closed, the electrolyte rises in the upper tank, thereby progressively short-circuiting the electrodes until the minimum resistance is reached at the overflow point, after which the liquid simply continues to circulate through the two tanks. A switch is provided so that this rheostat may be short-circuited.

The cables for connecting the turbogenerators and motors are of great importance, as the operation of the

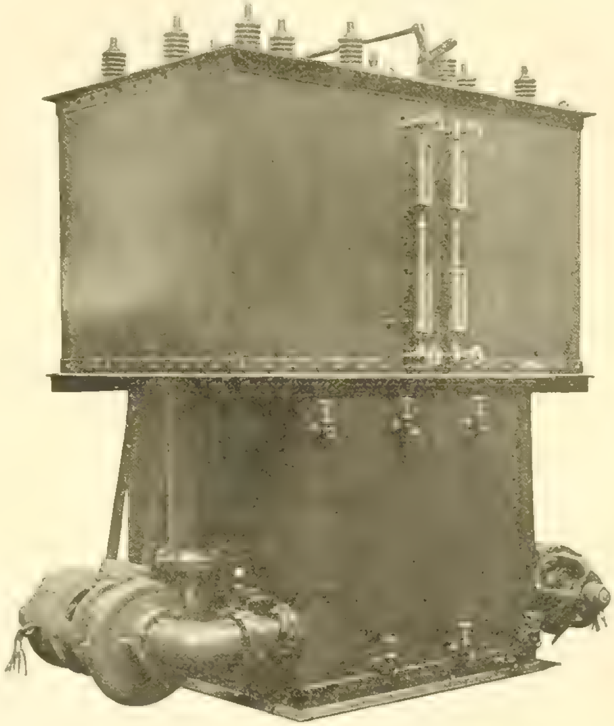


FIG. 4—DOUBLE LIQUID RHEOSTAT

For starting the main propelling motors.

ship depends upon their reliability. A number of parallel circuits are used, each cable being of the three-core type, and the failure of any single cable would not seriously interfere with the operation of the ship. The main cables are of the same order of importance as the main steam pipes; hence the greatest care has been taken to insure that these cables should be the best type that is possible to manufacture for the service and to this end, a committee of the American Institute of Electrical Engineers assisted the Navy Department in preparing the specifications.

The main auxiliaries in the engine rooms are electrically driven. The main circulating pumps are driven by 235 hp direct-current motors, directly connected to centrifugal pumps, the speed of which can be varied to suit various conditions of operation. In this way, the power consumption can be reduced as the

speed of the ship is reduced. The principal provision for maintaining vacuum in the condenser is the use of LeBlanc air ejectors, which are novel for this class of ship. These air ejectors have already been successfully tried out by the Navy Department on other vessels with such satisfactory results as to justify their adoption for these vessels. The condensate from the condensers is handled by vertical electrically-driven centrifugal condensate pumps so that the whole of the essential auxiliary apparatus for the turbines is rotary and, based on the experience in land service as well as at sea, a greater reliability and lower maintenance can be anticipated for these equipments compared with past practice. The use of air ejectors enables the vacuum to be maintained at least as high, if not higher, than the older combination of reciprocating air pump and Parsons augmentor, and the space and weight are a very small fraction of that required with the older system.

While steam consumption is not of vital importance, on account of the other advantages of electric drive, yet the figures that can be obtained are very appreciably better than the direct connected turbine and are lower than any past practice. The anticipated steam consumption of the propelling machinery including the power required for the ventilation of the motors, the main circulating pumps, the condensate pumps and excitation of the turbogenerators is shown in Fig. 3. It will be seen that from 10 to 15 knots, only one generator is used, the motors being connected for 36 poles. From 15 to 17 knots, the motors are connected for 24 poles and one generator is used. From 17 knots to 21 knots, both generators are in operation, each machine supplying power to two motors, each side of the ship being independently operated.

In designing the equipment for the *Tennessee*, every effort has been made to avoid the introduction of experimental or risky constructions, and the design is such that the experience gained in other fields has been utilized to full advantage, and the design factors have been kept within well-developed practice. At the same time provisions have been made so that the full advantages of the characteristics of electric drive can be utilized in the operation of the ship.

Industrial Controllers-XX

Car Dumpers

H. D. James

THE CAR DUMPER is a special machine designed for unloading ore or coal from open type railway cars. The apparatus consists of two essential parts—the barney haul and the cradle hoist.

A train of loaded cars is placed on a slight incline approaching the car dumper. An individual car is detached and passes down the incline to the barney haul, which consists of a small car with a pusher arm projecting above the track between the rails, attached to a cable driven by an electric motor. The arm engages the rear of the car and pushes it up an incline to the cradle hoist. The car is fastened securely in the cradle by clamps, shown in Figs. 2 and 4, which engage the top of the car and hold it firmly against the rails. These clamps consist of vertical members which are curved into hooks at the top. There are several of them on each side of the car, set high enough to clear the largest car and held down by counterweights, such as the small rectangular counterweights shown in Fig. 2. When the cradle is hoisted they engage the top of the car, exerting sufficient force to retain the car in place when the cradle turns it over. By the use of counterweights a very flexible form of clamping is obtained, which is entirely automatic in its operation. Clamping bars may be used instead of hooks as shown in Fig. 4. The cradle hoist lifts the car to a fixed elevation and turns it over, emptying the contents of the car onto an apron provided with a chute for directing the contents into the proper place. This method of unloading is used extensively in connection with coal and ore. The material may be loaded onto a conveyor, into a boat or a hopper car. The empty car is returned to the track level and the clamps removed. The next loaded car pushes the empty car onto an incline located on the other side of the cradle hoist. The empty car descends by gravity to an assembling track or switch, where it is taken care of in the usual way.

FIG. 1—CAR DUMPER

Showing the incline on the approach side. This dumper is used for loading coal into boats and is provided with a special form of pan and chute for this purpose.*

*Car Dumper built by McMyler Interstate Company.

BARNEY HAUL

The barney haul is usually operated by a direct-current compound-wound motor, although a series motor may be used where there is sufficient friction to eliminate any danger of over-speeding. The controller is usually of the rheostatic reversing type, provided with one armature shunt point to give a slow speed when the barney engages the car. A series or compound motor is able to exert the heavy torque required during the period of moving the car up the incline. On the reverse motion the weight of the barney is insufficient to overhaul the cable; it is therefore necessary to operate the motor drive in the reverse direction. A series or a compound motor gives a high speed return under this light load. In calculating the size of motor and control the heating effect is based upon the period of heavy load during hoisting and the light load on the return stroke. The motors run from 150 to 300 hp, at either 230 or 500 volts. The controller is of the magnetic contactor type Fig. 3. Limit switches are provided to stop the motor automatically at each limit of travel. Both the gear type and the track type limit switches have been used.

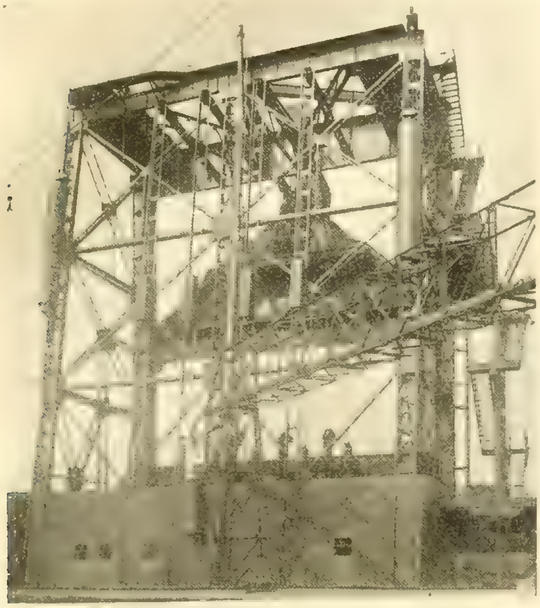
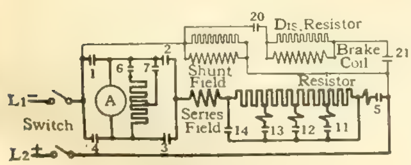


FIG. 2—BACK VIEW OF CAR DUMPER OF FIG. I

SCHEME OF MAIN CONNECTIONS



SEQUENCE OF CONTACTORS

Con	Dwn	Off	Up 1	Up 2	Up 3			
1			O	O	O	O	O	O
2	O							
3			O	O	O	O	O	O
4	O							
5	O		O	O	O	O	O	O
6			O	O				
7			O					
11					O	O	O	O
12						O	O	O
13							O	O
14								O
20	O		O	O	O	O	O	O
21	O		O	O	O	O	O	O

FIG. 3—DIAGRAM OF CONNECTIONS FOR BARNEY HAUL

CRADLE HOIST

The motors for the cradle hoist are of the direct-current series type. Sometimes a single motor is used, for other applications—two motors. Where the barney haul requires only half the horse-power of the cradle hoist, the use of three motors of the same rating makes a good arrangement. The armatures and other spare parts of the motors remain the same, the only difference being the field windings.

While the loaded car is being hoisted, the maximum amount of torque is required. After the proper height has been reached and the car begins to turn over, the load decreases but still remains positive due to the arrangement of counterweights. In returning the empty car the motor first operates under a friction load while swinging the cradle over to the upright position of the car. The cradle and car are then lowered under dynamic braking to the track level. The cradle is counterbalanced to make the work done during the total cycle as small as possible.

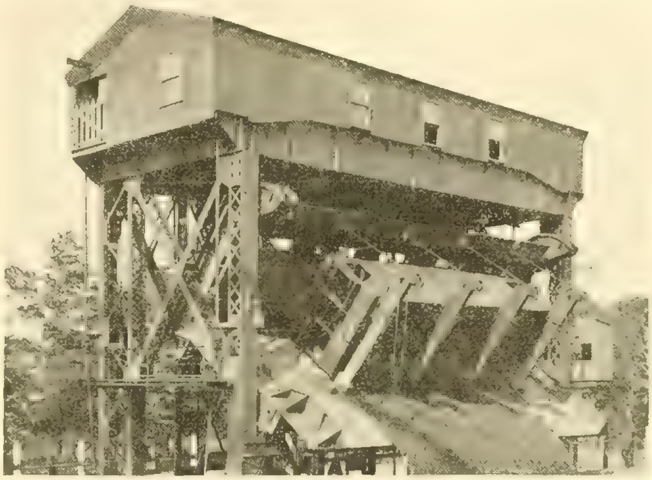
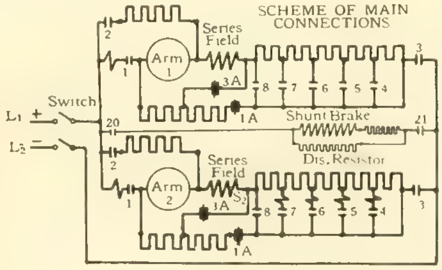


FIG. 4—CAR DUMPER DISCHARGING THE COAL FROM A CAR

The car is held against the track by means of bars instead of hooks.†

The controller connections, Fig. 5, provide for full reverse with dynamic braking in the lowering. The controller consists of magnetic contactors operated from a master switch. The limit of travel in both directions is controlled by limit switches, either of the gear or track type. The motors range in size from a total of 250 to 400 hp, sometimes divided between two

SCHEME OF MAIN CONNECTIONS



SEQUENCE OF CONTACTORS

Con	Hoist					Off	Lower					
1	O	O	O	O	O							
2							O	O	O	O	O	O
3	O	O	O	O	O		O	O	O	O	O	O
4	O	O	O	O	O		O	O	O	O	O	
5	O	O	O	O			O	O	O	O		
6	O	O	O				O	O	O			
7	O	O					O	O				
8	O						O					
1A						O	O	O	O	O	O	O
3A						O						
20	O	O	O	O	O		O	O	O	O	O	O
21	O	O	O	O	O		O	O	O	O	O	O

FIG. 5—SCHEME OF CONNECTIONS FOR CRADLE HOIST

Using two motors in parallel. Each motor has a separate set of resistors short-circuited simultaneously by double pole contactors. The acceleration is by current limit relays and the relay coils are shown in the circuit of No. 2 motor. The motors are geared together rigidly and must be accelerated as a single unit.

†Car Dumper built by Wellman-Seaver-Morgan Company.

motors. Usually the single motors do not exceed 350 hp.

The distance of the vertical hoist before the car is turned over depends upon the applications. In some cases this hoist may be 40 to 50 ft., in other cases only a short distance. Where the vertical travel is considerable, it is usually necessary to slow down the cradle where the motion changes from vertical to rotating. In coming back, the rotating motion is slowed down where it changes to vertical. This slowing down is to avoid shocks when the cradle enters and leaves the hooks or trunions.

The above description is general. It applies in the main to various commercial types of car dumpers, each particular design embodying ingenious features for taking care of the details. The arrangement of the barney differs with various companies. It is necessary to return the barney, so that it will pass underneath the next car. This may be done by a system of two track

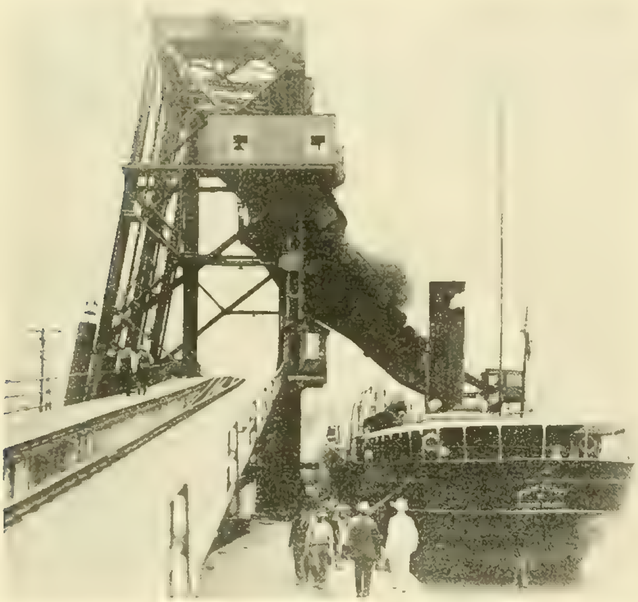


FIG. 6—CAR DUMPER LOADING COAL INTO A BOAT*

levels or by an arrangement for rotating the arm into a horizontal position during the return part of the travel. The details of changing the motion of the cradle from the vertical hoist to the rotating motion differ in various designs. The car dumpers illustrated in Figs. 1 and 6 employ an ingenious arrangement to permit the operator on the outer end of the pan to get back and forth to the main cab. It consists in a duplicate set of controllers for hoisting the pan so that the operator may bring the hinged end of the pan back on a level with the stationary cab and then raise the pan to a horizontal position to permit him to walk over his cab to the main cab. Various designs of pans or chutes are employed for directing the contents of the car in the desired manner.

*Car Dumper built by McMyler Interstate Company.

PAN OR APRON

Where the coal or ore is loaded into the vessel, an adjustable pan or apron provided with a chute is furnished, the nozzle of which can be turned in different directions. This arrangement is illustrated in Fig. 1.

FIG. 7—CAR DUMPER ARRANGED FOR DUMPING COAL OR ORE INTO A YARD

Separated from the track by a wall. The coal or ore is taken from this point by a bridge with a grab bucket. This form of car dumper is arranged for moving along the wall and is carried on a special track.†

The pan is raised or lowered by a pair of screws, one of which is attached to each upright. These screws are driven by reversible motors with the ordinary rheostatic control. The pan is hinged to the two uprights of the car dumper and the outer end is raised or lowered by means of an electric motor. The control for this motor is similar to the control for the cradle hoist, only much smaller. It provides for rheostatic control in the hoisting direction and dynamic braking in lowering.

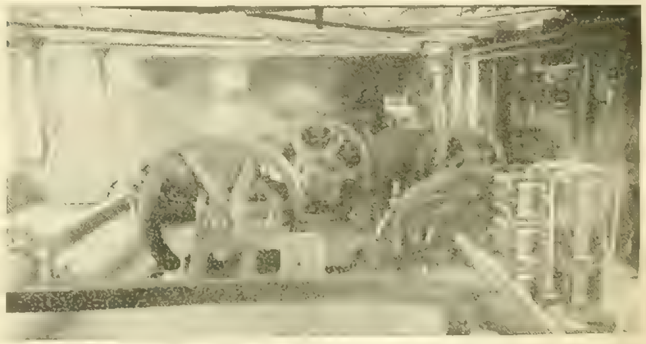


FIG. 8—MOTORS AND CONTROLLERS FOR OPERATING CAR DUMPER

The chute is provided with a small motor for rotating it. The operator is located in the cab immediately above the chute and controls the height and location for the opening in the chute by means of the controllers just described.

†Car Dumper built by Wellman-Seaver-Morgan Company.

The Essentials of Transformer Practice-XIII

Conditions for Minimum Cost of Operation

E. G. Reed

THE discussion in section XII related to the calculation of the total yearly cost of operating a transformer while the present section is concerned with the relations of its various characteristics which will make the total yearly cost of operation a minimum. As in the previous case the conclusions reached depend upon the assumptions made as to cost of power, cost of transformer and conditions of load. Therefore no general answer can be made which will be applicable to all cases, and if the data as to the average conditions of a large number of cases at a given time are obtained the solution is still not a general one as the relative values of the various constants are continually changing.

RATIO OF COPPER TO IRON LOSS TO MAKE THE YEARLY COST OF THE LOSSES A MINIMUM

In order to get a definite idea as to the conditions which make the total cost of operation a minimum, with change of the ratio of the losses, the subject may be treated analytically as follows. The cost of the exciting current cannot easily be brought into the relation, but since its cost is the smallest element of the total, its omission does not greatly change the result.

If on the same frame the iron loss is increased, the exciting current increases. When the copper loss increases, the regulation becomes poorer, particularly with loads of high power-factor. The relation between the losses of a transformer of fixed output on a given frame, and therefore of constant cost, as given in section IV, equation (7), is as follows:—

$$L_c\, L_1 = \text{Constant} \quad \ldots\ldots \quad (1)$$

Where L_c is the copper loss by wattmeter at 75 degrees C., and L_1 is the iron loss.

The relation between the losses is indicated by r when, —

$$r = \frac{L_c}{L_1} \quad \ldots\ldots \quad (2)$$

Combining equations (1) and (2),

$$L_1 = \frac{\text{Constant}}{\sqrt{r}} \quad \ldots\ldots \quad (3)$$

The costs of operating the transformer which vary with the ratio of the losses, aside from the exciting current are, from section XII, equations (2) and (5),—

$$\text{Dollars per year} = L_1\,(p+d) + L_c\,(pF+d) + 20\,RPFk$$

Where p and d are the production and fixed charges respectively for producing electrical energy and F is the quantity which, multiplied by the copper loss at normal load, gives the actual continuous copper loss over the daily load curve.

Restricting the solution to a load of 100 percent power-factor, this may be written—

$$\text{Dollars per year} = L_1\,(p+d) + L_c\,(pF+d) + 2\,L_cFk$$

Substituting the value of L_c from equation (2), gives,—

$$\text{Dollars per Year} = L_1\,[(p+d) + r(pF+d) + 2\,rFk]$$

Substituting the value of L_1 from equation (3), gives,—

$$\text{Dollars per year} = \text{Constant}\left[\frac{(p+d)}{\sqrt{r}} + \sqrt{r}\,(pF+d) + 2\sqrt{r}\,Fk\right]$$

Differentiating this expression with respect to r and putting the differential coefficient equal to zero gives,—

$$r = \frac{(p+d)}{pF+d+2\,Fk} \quad \ldots\ldots \quad (4)$$

TABLE I—TOTAL YEARLY COST OF OPERATING A FIVE K.V.A. TRANSFORMER

r	Iron Loss	Copper Loss	Percent Exciting Current	Percent Regulation	Investment Charge	Cost of Iron Loss	Cost of Copper Loss	Cost of Exciting Current	Cost of Regulation	Total Yearly Cost
1.0	64.8	64.8	6.0	2.04	$5.61	$5.51	4.36	0.22	1.89	15.27
1.5	53.0	79.2	3.0	2.29	5.61	4.51	4.00	0.24	1.79	15.12
2.0	45.8	91.7	2.2	2.52	5.61	3.90	3.57	0.29	1.67	15.04
2.5	41.0	102.5	1.75	2.71	5.61	3.48	3.09	0.38	1.51	15.10
3.0	37.5	112.0	1.6	2.87	5.61	3.19	$2.53	$0.66	$1.35	$15.66

Example 1—What is the value of the ratio of the losses to make the cost of the losses a minimum, for a 5 k.v.a. transformer operating under the following conditions:—

$$\text{where } L_1 = 42;\ F = 0.167;\ L_c = 100;\ \text{and } k = 0.04$$
$$p = 0.055$$
$$d = 0.03$$
$$p+d = 0.085$$
$$pF+d = 0.039$$
$$\text{Cost of transformer} = \$51.00$$
$$\text{Annual interest charge, } i = 0.11$$

From equation (4),— $r = \dfrac{0.085}{0.0390 + 0.0131} = 1.62$

The values of the losses to give this ratio are,— $L_1 = 51$ and $L_c = 82$

To get the actual minimum cost of operating the transformer the cost of the exciting current must be taken into account. The cost of the exciting current for a transformer fully loaded continuously is a matter of some importance, but of smaller importance when the transformer is operated at full load only a portion of the time.

The total cost of operating the five k.v.a. transformer with different ratios of the losses, using the same frame in all cases is given in Table I.

When the cost of the exciting current is taken into account, the ratio of the losses becomes closer to a value of 2 as shown by the table, than the case in Ex-

ample 1, where the exciting current is ignored. Table I, also gives the investment charge, which is a constant quantity and therefore does not affect the point of minimum total cost with variation of the ratio of the losses. In calculating this table a five k.v.a. transformer frame was used which was designed for a ratio of the losses between 2 and 2.5. When this frame is worked at a magnetic density which raises its iron loss up to equality with the copper loss, a relatively high exciting current results. This keeps the point of minimum yearly total cost of operation at a higher ratio of copper to iron loss than would result if the frame were designed for a higher iron loss.

The striking point brought out by Table I is that the total cost of operating the transformer changes very slowly from a minimum charge of $15.04 for a ratio of *2*, for increasing or decreasing values of the ratio of the losses. For example, changing the ratio from *2* to *1.5*, the cost increases $0.06 or less than one percent of the yearly cost of operation. Changing the ratio from *2* to *2.5*, a correspondingly low increase in the yearly cost is found. This would indicate that attempts to secure low iron in distributing transformers has perhaps been overdone, when the low iron loss is secured by increasing the copper loss and regulation. The really important item in comparing the relative economy of two transformers is the product of iron and copper losses, assuming of course that the exciting current has a reasonably low value, and the ratio of the losses is between *1.5* and *2.5*.

It is evident from equation (4), that r increases when F or k decreases, and when p increases. Changes in the value of d will have a relatively small effect on the value of r. It is also evident that when F becomes unity, that is the transformer is fully loaded continuously, the value of r becomes less than unity. Fig. 1 shows the variation of the value of r, with changes of F, when p, d and k have values as given in the examples already given.

THE MOST ECONOMICAL OUTPUT RATING OF A GIVEN TRANSFORMER

The examples which have been given consider transformers of fixed output and have calculated the yearly cost of operation including the investment charge, the cost of the losses and the regulation. It will be interesting to determine if a given transformer can be operated economically at other than its normal rated output. This can be analyzed by permitting the output of the transformer to vary and determining the rating which will make the total cost per k.v.a. output a minimum.

Example 2—What is the most economical output rating of the transformer covered by Example 1? This problem is analyzed in Table II.

It is evident from Table II that with the constants assumed, the transformer could be operated with a minimum cost per k.v.a. output somewhere between six and seven k.v.a. However, the curve is very flat in this region and the increased cost per k.v.a. output from seven to five k.v.a. only about five percent. Also, aside from the question of economy, the regulation for the higher ratings becomes objectionable from the point of view of service, also questionable because of considerations of heating, and finally a normally rated 7.5 k.v.a. transformer will have a lower cost of operation per k.v.a. output than the five k.v.a. transformer covered by Example 2.

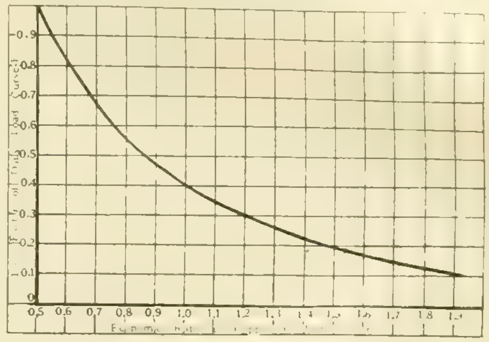


FIG. 1—VARIATION OF THE ECONOMIC RATIO OF COPPER TO IRON LOSS WITH CHANGES OF LOSS FACTOR OF THE LOAD CURVE

Example 3—What is the cost of operation of a 7.5 k.v.a. transformer which has a cost of $66.00 and the following performance characteristics?

$L_i = 57$; $L_c = 132$; $m = 0.0155$; and regulation at 90 percent power-factor = 2.63.

1—Investment charge	$ 7.26
2—Cost of iron loss	4.85
3—Cost of copper loss	5.15
4—Cost of exciting current	0.33
5—Cost of regulation	2.64
Total	$20.23

This gives a cost of $2.70 per k.v.a. output, which is less than the minimum cost per k.v.a. output of the five k.v.a. at an increased output in the neighborhood of seven k.v.a. Further, this 7.5 k.v.a. transformer does not have the objectionable features of over-heating or bad regulation as does the five k.v.a. unit when operated at the higher rating.

There are, however, cases arising in practice where there is only one transformer available for a particular service and in such cases it is important to know the most economical load which the unit should carry under the particular operating conditions. This load may be determined analytically as follows, but care should be used not to select a rating which will give an objectionable regulation from the point of view of service, or one which will overheat the transformer.

The total cost of operating the transformer is:—

TABLE II—TOTAL YEARLY COST PER K.V.A. OUTPUT OF OPERATING A GIVEN TRANSFORMER

K.V.A. Output	Iron Loss	Copper Loss	Percent Exciting Current	Percent Regulation	Investment Charge	Cost of Iron Loss	Cost of Copper Loss	Cost of Exciting Current	Cost of Regulation	Total Cost	Cost per K.V.A.
4	42	64	2.25	2.14	$5.61	$3.57	$2.5	$0.25	$1.14	$13.07	$3.26
5	42	100	1.8	2.67	5.61	3.57	3.9	0.25	1.76	15.09	3.02
6	42	144	1.5	3.21	5.61	3.57	5.62	0.25	2.53	17.58	2.93
7	42	196	1.28	3.74	5.61	3.57	7.65	0.25	3.44	20.52	2.87
8	42	256	1.12	4.27	5.61	3.57	9.99	0.25	4.47	23.89	2.99

$$\textit{Dollars per year} = iC + L_i\,(p+d) + K + L'_c\,(pF+d) + 2L'_c Fk$$

Dollars per Year per k.v.a. =

$$\frac{iC + L_i\,(p+d) + K + L'_c\left[(pF+d) + 2Fk\right]}{P'} \quad \ldots\ldots (5)$$

Where P' is the most economical rating under the assumed conditions, C is the cost of the transformer in dollars, i is the investment rate, expressed decimally, K is the constant cost of the exciting current and L_c' is the copper loss, at operating temperature, associated with this rating. In substituting $L_c' \div P'$ for the regulation of the transformer, the solution has been restricted to a 100 percent power-factor load, as far as the effect of the regulation is concerned.

Evidently the value of P' desired is the one which will make the value of equation (5) a minimum. Before differentiating this equation with respect to P' as the variable, it will be necessary to obtain an expression for the variable L_c' in terms of P'. By definition $P' = E'\,I'$, where E' and I' are the voltage and current output associated with the output P'. Also $L_c' = I'^2\,R'$, where R' is the equivalent resistance of the primary and secondary windings of the transformer at operating temperature with load P'. From these two equations,— $L'_c = \left(\frac{P'}{E}\right)^2 R'$.

Substituting this value of L_c' in equation (5), gives,—

Dollars per year per k.v.a. =

$$\frac{iC + L_i\,(p+d) + K + \left(\frac{P'}{E}\right)^2 R'\left[(pF+d) + 2Fk\right]}{P'}$$

Differentiating this expression with respect to P', and putting the differential coefficient equal to zero gives,—

$$P'^2 = \frac{E^2}{R'}\left[\frac{iC + L_i\,(p+d) + K}{(pF+d) + 2Fk}\right]$$

Multiplying through by the normal rated current I squared, gives,—

$$P'^2 = \frac{E^2 I^2}{I^2 R'}\left[\frac{iC + L_i\,(p+d) + K}{(pF+d) + 2Fk}\right]$$

Since $P = EI$, this equation may be written,

$$P'^2 = \frac{P^2}{I^2 R'}\left[\frac{iC + L_i\,(p+d) + K}{(pF+d) + 2Fk}\right]$$

Multiplying both numerator and denominator by $\frac{R}{R'}$, gives,—

$$P'^2 = \frac{P^2\,\frac{R}{R'}}{I^2 R}\left[\frac{iC + L_i\,(p+d)}{(pF+d) + 2Fk}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

But $L_c = I^2R$, where L_c is the copper loss of the transformer in watts at normal output P and R is its equivalent resistance at the temperature resulting from operation at output P. Then equation (6) becomes,—

$$P' = P\left\{\frac{\frac{R}{R'}}{L_c}\left[\frac{iC + L_i\,(p+d) + K}{(pF+d) + 2Fk}\right]\right\}^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots (7)$$

Example 4. What is the most economical output rating of the five k.v.a. transformer in Example 2?

From equation (7), assuming that the ratio $\frac{R}{R'}$ is unity,—

$$P' = 5\left\{\frac{1}{100}\left[\frac{0.11 \times 51 + 12 \times 0.085 + 0.25}{0.039 + 0.0134}\right]\right\}^{\frac{1}{2}} = 6.7$$

It is obvious that the value of $\frac{R}{R'}$, which is the ratio of the equivalent resistance of the transformer when operating at normal rating to the resistance when operating at an output of P', is less than unity. An exact determination of this ratio is practically impossible, but it will be assumed that the average temperature of the transformer in this particular case at an output of P' is 20 degrees C higher than with an output of P. This gives a value for the ratio $\frac{R}{R'}$ of approximately 0.93. Solving equation (7) again with this value of $\frac{R}{R'}$ gives the most economical rating as 6.5 k.v.a.

This checks the result secured from Example 2. The value of the output rating given by Example 4 is somewhat greater than that given by 2, because equation (7) considers the regulation at 100 percent power-factor load while Example 2 contemplates regulation at 90 percent power-factor. The regulation at 90 percent power factor being poorer than at 100 percent, the charge for regulation is greater in the former case. An inspection of equation (7) indicates that the economical output rating increases with the investment, iron loss and exciting current costs, and decreases as the copper loss and regulation costs become greater.

TABLE III—COMPARATIVE COSTS OF OPERATING TWO TRANSFORMERS

K. v. a.	Iron Loss	Copper Loss	Percent Exciting Current	Percent Regulation	Investment Charge	Cost of Iron Loss	Cost of Copper Loss	Cost of Exciting Current	Cost of Regulation	Total Yearly Cost
5	42	100	1.8	2.67	\$5.61	\$3.57	\$3.90	\$0.25	\$1.76	\$15.09
5	49	98	1.8	2.63	4.98	4.17	3.83	0.25	1.74	14.97

RELATION OF THE COST OF A TRANSFORMER AND ITS LOSSES TO MAKE THE TOTAL COST OF ITS OPERATION A MINIMUM

The preceeding discussion has made no reference to the relation existing between the cost of a transformer and its losses. In a particular case a given transformer might be economically replaced by one of higher cost and reduced losses, or one of lower cost with increased losses. In order to analyze this phase of the subject it is necessary to know the relation between the cost of the transformer and its losses. This relation may be expressed algebraically as follows, which is the same as that in equation (12), section XI.

$$C = \frac{K'}{(L_i + L_c)} + C' \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where K' is a constant and C' that part of the cost of a transformer which does not vary with its losses, as its design is changed.

The total yearly cost of operating a transformer aside from the cost of the exciting current has been shown to be,—

$$\text{Dollars per year} = i\,C + L_i\,(p+d) + L_c\left[(p\,F+d) + 2\,F\,k\right] \quad (9)$$

Substituting the value of C from equation (8) and the value of L_c from equation (2) in equation (9),—

$$\text{Dollars per year} = \frac{i K'}{(L_i\, r)^2} + i\,C' + L_i \left\{ (p+d) + r\left[(pF+d) + 2Fk\right] \right\}$$

Differentiating this equation with respect to L_i and putting the differential coefficient equal to zero,—

$$L_i = \left\{ \frac{2\,i\,K'}{r^2 \left\{ (p+d) + r\left[(r\,F+d) + 2\,F\,k\right] \right\}} \right\}^{0.25} \quad (10)$$

If we take r to be equal to 2, then

$$L_i = \left\{ \frac{1.06\,i\,K'}{(p+d) + 2\left[(p\,F+d) + 2\,F\,k\right]} \right\}^{0.25} \quad (11)$$

From equation (11) it is apparent that a considerable change in the quantity whose exponent is 0.25 is required to materially change the value of L_i. For example, increasing its value ten percent, increases the value of L_i only two percent, and decreasing its value ten percent, reduces the value of L_i only two percent.

Example 5—What should be the cost and losses of a five k.v.a. transformer, based on the conditions given in the previous examples? The value of K′ to be taken from a five k.v.a. transformer whose cost is \$51.00, and whose losses are,—

$$L_i = 42 \text{ and } L_c = 100$$

It will be assumed that the cost of the active material in the transformer is 65 percent of \$51.00 or \$33.25. From equation (8); $K' = 33.25\,(42 \times 100)^2 = 905 \times 10^4$

Then from equation (11),

$$L_i = [illegible]$$

$$L_c = 2 \times 49 = 98.$$

The new cost from equation (8) will be—

$$C = \frac{905 \times 10^4}{(49 \times 98)^2} + 17.75 = \$45.25$$

An actual comparison of the cost of operating these two transformers gives the results shown in Table III.

*The author is indebted to Mr. J. B. Gibbs for assistance in the preparation of this section.

The Engineering Evolution of Electrical Apparatus—XXXI

The History of Indicating Meters

CHAS. R. RIKER

THE PULL exerted upon an iron core by a solenoid was one of the earliest electrical phenomena observed, and it was only natural that when the development of the electrical industry produced a demand for measuring instruments, this principle should have been used. A wide variety of such instruments was produced prior to 1890. In several of these a straight vertical pull was balanced against the pull of gravity by some such device as that shown in Fig. 17. These instruments were known as the glass and marble type, although the earlier instruments brought out about 1886 were made in a wooden frame with glass sides.* The essential element of these instruments consisted of a core of soft iron wire which was drawn into a long solenoid by the current to be measured. To avoid friction the moving element was supported on knife edges, as in a balance, the weight of the iron core being balanced by an adjustable brass weight or a hollow cup filled with shot. A plumb bob was provided inside the case to insure accurate leveling. In the earlier voltmeters, only one point was provided on the scale, which represented the correct voltage for the system. A slide wire resistance at the right provided for adjustment of this voltage, the main resistance element being mounted on a card at the rear of the instrument. Later on as it became necessary to provide ammeters with a complete scale, it became customary to provide a scale on the voltmeters, usually with a depressed zero as shown in Fig. 18.

With this type of ammeter the main current always passed through the instrument, so that on instruments of large capacity the coil was reduced to one turn of considerable size. These instruments had no damping device. Such an ammeter would be impossible to-day on account of the heavy generating capacity in the stations; the first short-circuit would tear it to pieces. In a later form the iron core of these instruments was modified to consist of sections of soft iron supported at intervals along a central rod, as shown in Fig. 18, thereby securing a more uniform scale.

In another variety of solenoid instrument—called the "steelyard" ammeter, the pull of the solenoid was balanced by a sliding weight on a steel yard lever, to the opposite end of which the iron core was attached. In another ingenious instrument, a fixed iron core in the solenoid attracted an eccentrically pivoted disc of iron, causing it to rotate against the action of gravity. Still other instruments used curved cores of various forms, adapted to rotary motion, the core support being pivoted at the side of the coil. Usually the restraining force was gravity, and hence the instruments were suited only for laboratory or switchboard purposes. An instrument of this type which was designed for portability is shown in Fig. 19. The weights of the moving parts were balanced so as to be independent of its position and motion was restrained by a spring. In this instrument, the effects of the heating of the coils on the registration were minimized in two ways:—the resistance external to the coils was so great that the effects of variation of the coil resistance were almost negligible;

*As shown in Fig. 7, p. 33, Jan. 1914 and Fig. 1, p. 320, July 1915.

and the resistance of the circuit was divided into two parts having opposite temperature coefficients which practically neutralized one another.

Another popular meter of this type was the Ayrton and Perry meter shown in Fig. 20 which was based on

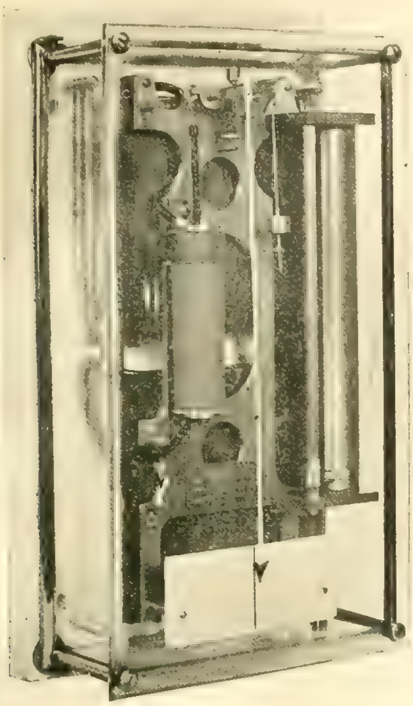


FIG. 17—EARLY "GLASS AND MARBLE" ALTERNATING-CURRENT VOLTAGE INDICATOR

the fact that one end of a flat spiral spring will rotate when the spring is stretched, with the other end fixed, the angle being considerable for a small extension, and being proportional to the amount of stretching. The spiral spring *S* was fastened at its upper end to the stationary head *H* and at its lower end was attached to a soft iron tube *T* which formed the core of the solenoid *W*, the tube being free to rotate, carrying with it a pointer. Because the tube remained practically in the same position relative to the solenoid throughout the entire range of scale; and because it was so thin as to become saturated at low magnetizations, the scale was

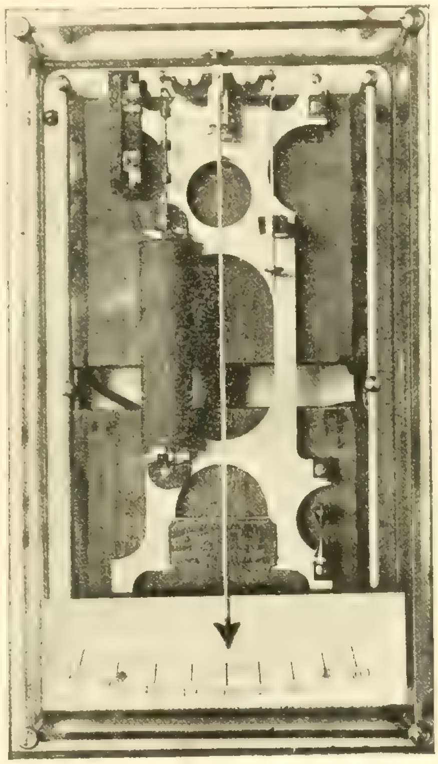


FIG. 18—LATER VOLTMETER, HAVING DEPRESSED ZERO SCALE AND IMPROVED CORE

uniform except over the lowest readings. A mirror was provided to avoid parallax errors and a compass to indicate polarity, an iron casing surrounded the coils as a protection from external fields. This instrument was in common use prior to 1890. This same action of a spiral spring, or of two such springs oppositely twisted and joined end to end, was also used in a variety of instruments both of the solenoid and of the hot wire type.

A more modern form of solenoid instrument in

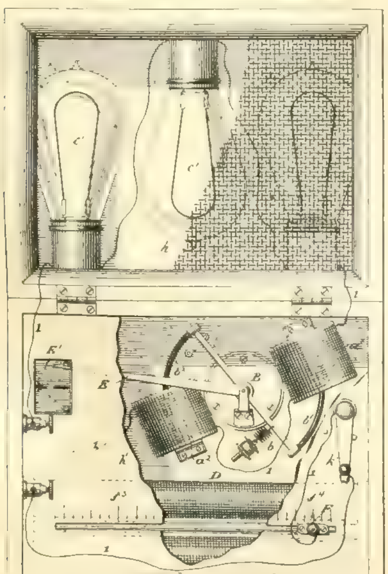


FIG. 19—LANGE PORTABLE VOLTMETER

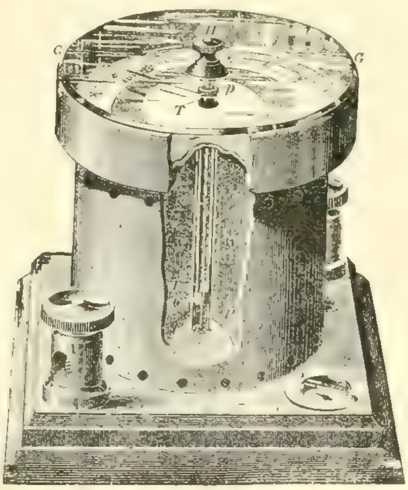


FIG. 20—AYRTON AND PERRY IRON HELIX AMMETER

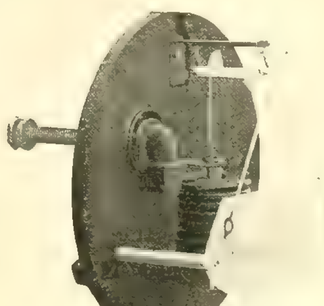


FIG. 21—KELVIN SECTOR AMMETER

which the same principles of saturated magnetic circuit and small total motion of the core are utilized is shown in Fig. 21. By suitably proportioning the sector from which the core is suspended and the location of the counter balance, practically a uniform scale was produced.

Magnetic Vane Instruments—As was true of most of the earlier measuring instruments, the magnetic vane type was first developed in Europe. A characteristic instrument of this type was the Shuckert ammeter, shown in Fig. 22. A thin curved plate of soft iron, shown at the right was attached to a light steel spindle, pivoted so as to lie parallel to and a little to the left of the axis of the coil. The attraction of the coil tends to move the iron vane toward the center of the coil. Calibration and adjustment of zero were affected by bending a small piece of copper wire attached at one end to the spindle.

Another type of magnetic vane instrument, developed prior to 1887 by Imhoff, depended on the mutual repulsion between two strips of soft iron in a solenoid carrying the current to be measured—one being stationary and the other pivoted in the axis of the coil on agate jewels and provided with a copper pointer. The two vanes were magnetized in the same sense by the current in the coil and a mutual repulsion took place which was proportional to the square of the current. A supplementary piece of soft iron was wrapped about the interior of the coil to provide a more proportional scale. This meter was put on the American market by Queen and Company in 1888. The same principle was later utilized, with a modified form of vanes, by the Weston Company.

Another interesting meter, shown in Fig. 23, depended on the tendency of a piece of soft iron to follow the leakage flux outside the solenoid. A relative large soft iron core had a tubular orifice through its length, at one side, in which was pivoted a cylindrical soft iron armature having straight soft iron extensions fixed at right angles at each end, one of them being shown hanging vertically downward in Fig. 23, with a pointer attached. Current in the coil tended to rotate the armature against the action of gravity. At first the scale was calibrated in degrees, and a calibration table accompanied each meter but later the scale was made direct reading.

The simplest form of magnetic vane instruments, and the one which has met with the greatest commercial success, is that in which a very thin, light weight vane of soft iron tends to set itself in line with the lines of flux. Instruments of this type are shown in Figs. 24 and 25. By suitably proportioning the shape of the vane and its position in the coil the scale was made fairly proportional throughout the working range. In these ammeters the entire current passed through the instrument. In the Thomson magnetic vane instrument, the coil was inclined with respect to the axis of the moving element in order to get a longer scale reflection. The movements of the needle of the instrument shown in Fig. 24 were not damped in any way, but the spring stop at both ends of the scale was intended to prevent bending the needle in case of a sudden excessive current. Instruments of this general type were standard for switchboard service for many years.

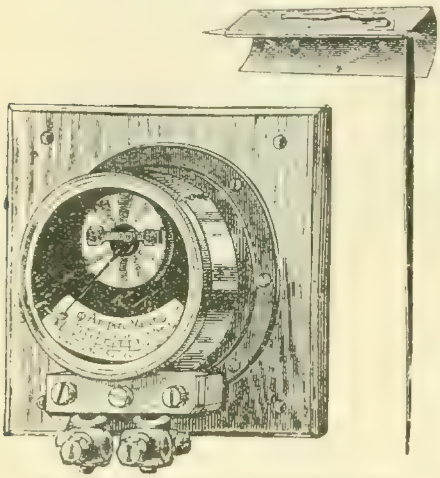


FIG. 22—SHUCKERT MAGNETIC VANE AMMETER

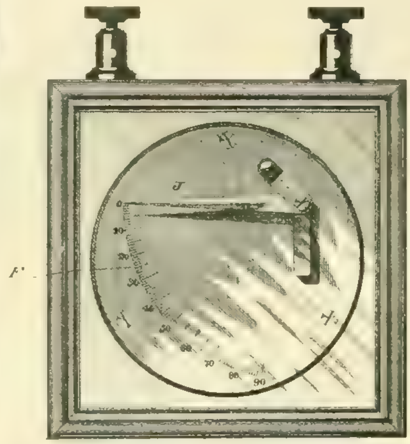


FIG. 23—WATERHOUSE AMMETER

FIG. 24—EARLY WESTINGHOUSE "ROUND TYPE" MAGNETIC VANE VOLTMETER

INDUCTION VOLTMETERS, AMMETERS AND WATTMETERS

The development of the Shallenberger amperehour* and watthour meters introduced a new principle into indicating meter design which was first taken advantage of in the instruments designed for the Niagara Falls Power Company in 1895. In fact the Niagara Falls wattmeter consisted essentially of a Shallenberger watthour meter, the rotation of whose disc was restrained by a spring. The deflection of the disc was therefore directly proportional to the watts. A paper scale was mounted on the edge of the disc which rotated behind a stationary pointer as shown in Fig. 26. The ammeter was likewise similar to the Shallenberger ampere-hour meter and the voltmeter was simply an ammeter in which the coil was wound with many turns of fine wire and provided with a series resistance. The

*To be described in a later article.

disc was also provided with several C-shaped damping magnets. This group of meters formed the first horizontal edgewise dial instruments ever made and represented the first commercially successful attempt at

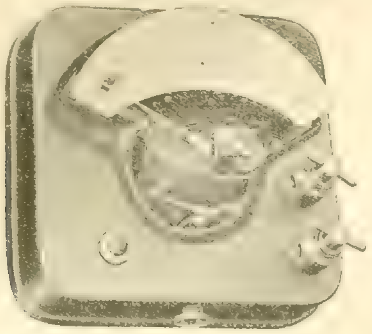


FIG. 25—THOMSON INCLINED COIL MAGNETIC VANE AMMETER

This instrument is damped both by a light fan attached to the pointer moving in an enclosed air chamber; and by a light piece of wire which rubbed against the pointer when the damping button was pressed.

getting the maximum possible scale length, this being the only type of instrument suitable for a scale extending approximately 360 degrees.

One great difficulty with the Niagara instrument was that the scale was difficult to read at a glance, as the numbers required careful inspection, and it was impossible to obtain an estimate of the load by the position of the pointer. The only modern representative of this system is the magnetic form of speedometer in common use on automobiles. To overcome this scale difficulty the scale was shifted so as to be parallel to the disc, as shown in Fig. 27, a needle was mounted on

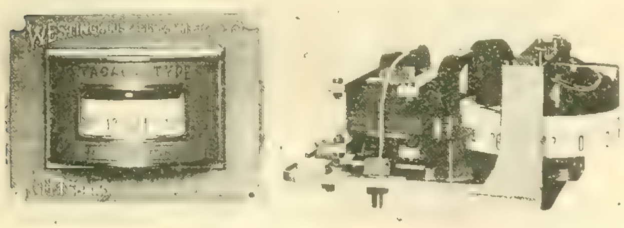
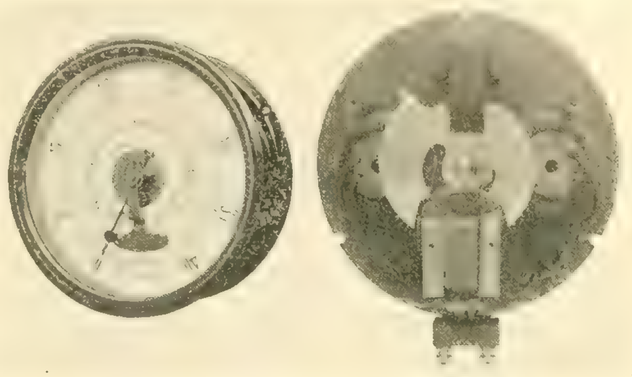


FIG. 26—NIAGARA TYPE INDUCTION INDICATING WATTMETER

the disc shaft and the scale made stationary. In this type of instrument the discs of the ammeters and voltmeters were made of a spiral shape, as shown in Fig. 28, so as to provide a smaller path for circulating currents at the higher points of the scale, and thus secure a more uniform scale division than that in the earlier instruments, in which the deflection was proportional to the square of the current. This spiral shape also improved the characteristics of the instrument with varying frequency and temperature. The great advantage of this type of meter over all its predecessors was the exceedingly long scale, over 300 degrees, allowing for an increased legibility, while the fact that the entire needle was in view all of the time allowed an approxi-



FIGS. 27 AND 28—WESTINGHOUSE DISC TYPE INDUCTION AMMETER

mate indication of the reading to be observed at a glance.

This type of induction meter was later superseded by the type shown in Fig. 29. In this meter frequency and temperature errors are eliminated automatically without any corrective devices by means of a series transformer with a non-inductive copper resistance secondary. At the same time this scheme provided a rotating field without using the phase splitter. The

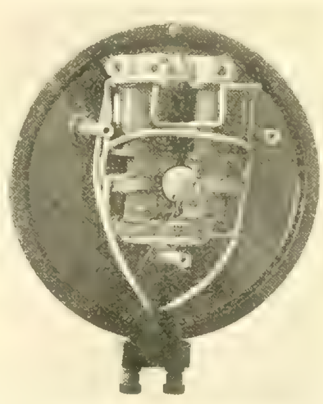


FIG. 29—WESTINGHOUSE DRUM TYPE INDUCTION AMMETER

moving element consisted of a very light aluminum drum which with spring and pointer weighs only six grams. The mechanism is simple and rugged, and its calibration is permanent.

CORRECTION

The caption of the upper cut, left column, p. 272, in the July, '18 issue should read "FIG 3—AYRTON AND PERRY PERMANENT MAGNET AMMETER".

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

AUGUST 1918

Flashing of Railway Motors

Flashing [illegible] railway motors, also commonly known as bucking or flashing, is primarily caused by poor commutation which results in a sudden breakdown of the insulation over the face of the commutator from the brushholder to the motor frame or ground. As a result, there is a sudden rush of heavy current which will either open the circuit breaker, or hang on as an arc, and badly burn the parts short-circuited.

The results of flashing are varied. Sometimes the motor is so badly damaged that it is inoperative. In this case, the motor must be overhauled, armature windings repaired, commutator cleaned up, brushholders and wiring-around-frame put in good condition. When the short-circuit is immediately cleared, the motor generally can be continued in service to finish its run, but should be reported as defective, and given a careful inspection for any damaged parts that need attention.

In Table I is given a detailed layout of the various conditions that affect commutation of a railway motor which in turn, influences its flashing.

TABLE I—CONDITIONS THAT TEND TO PRODUCE FLASHING

Design	Non-commutating pole type	
	Sensitive neutral	
	High voltage between commutator bars	
Commutators.	Rough face	High bars
		Low bars
		Loose bars
		Flat spots
	Poor surface condition	Poor undercutting of mica
		Sharp edges on commutator bars
		Sharp corners on commutator bars
		Dirty commutators
Brushholders.	Lack of spring tension.	Broken spring
		Weak spring pressure
		Pressure finger sticking
		Worn mechanism
	Incorrect setting.	Too far from commutator surface
		Incorrect spacing between brushholders
		Out of alignment with pole
	Worn carbon box	
	Loose in clamping block	
	Too small clearances to ground	
Carbons.....	Inferior grades	
	Length..............	Too long
		Too short
	Clearance............	Loose in carbon box
		Tight in carbon box
	Broken	
Windings. . .	Wiring around frame	Loose brushholder connection
	Armature............	Wrong connection
		Short circuited coil
	Main field	Reversed coil
		Field control—wrong connection
		Design of coil bobbin or case
	Commutating-pole field.	Short circuited coil
		Reversed coil
Operation.	Sudden voltage changes	Faulty control
		Rapid acceleration
		Plugging motors
		Heavy operation
		Breaks in third rail
	High-speed running	
	High trolley voltage	
	Overheating of motors	
	Loose or worn bearings.	Too much end play
		Too much side play
	Rough track	
	Flat wheels	

REMEDIES

Design—

[illegible] cannot be changed without practically rebuilding [illegible] replacing it by a modern motor in which the objectionable features have been eliminated.

Commutators—

1—The commutators should be tight, and have a smooth highly polished clean face.

2—[illegible] commutator should be heated and the ringnut or clamping bolts drawn up tight.

3—All high or low bars, and flat spots should be ground smooth if possible; otherwise the armature should be put in a lathe and turned.

4—The mica should be undercut to a depth of 3-64 inch, and all particles of mica thoroughly cleaned out of the slot.

5—If the sharp edges left on the copper segments when undercutting are rounded off, this will improve conditions.

6—The corners at the outer edge of the commutator face should be rounded off with approximately 3-16 inch radius, and those at the inner edge of the commutator face with approximately 1-16 inch radius.

7—The commutator [illegible] and dust.

Brushholders—

1—On the average, the tension on carbon brushes should be kept at approximately 5 to 7 pounds per square inch.

2—[illegible]

3—When the spring [illegible] spring.

4—If the mechanism tends to stick, a little signal oil on moving parts may relieve this; if not, take the brushholder apart, clean and machine parts that are tight.

5—When parts are badly worn, allowing the contact tip to rest on top of the carbon box, replace the worn parts by new pieces.

6—Brushholders should be set approximately [illegible] face of the commutator, and the sides of the box should line up parallel with the commutator segments.

7—The distance between brushholders measured around the surface of the commutator should be one-fourth of the number of bars.

8—With but few exceptions, the brushholder carbon box should line up with the center line of the pole.

9—A carbon box which is worn wider than normal will allow the brush to swing off the neutral. In double end operation due to uneven wear in running in different directions, the contact area is also considerably reduced. New brushholders will remedy trouble from this cause.

10—Brushholders should have at least 5/8 inch to 3/4 inch clearance to ground. When clearance is less than 5/8 inch, insulating arc shields, properly located, can be used to advantage.

11—Lining the inside of the motor frames around the brushholders, and at the commutator front V-ring, with insulating material tends to reduce flashing at these points.

Carbons—

1—Poor commutation can sometimes be greatly improved by changing to a higher grade of carbon brush.

2—If the carbons are too long, the resultant pressure from the brushholder contact tip is not on the top of the carbons, and the effective force on top of the carbons is reduced. For the more recently designed brushholders, carbons when new, should be two inches long.

3—When the carbons are too short the pressure on top of carbon is reduced, due to the design of the spring, and sometimes when the carbon is very short, it is entirely out of range of the spring, which strikes the side of the box. These carbons should be replaced by new ones.

4—Loose carbons cause vibration and tend toward poor commutation. Use new carbons with 0.006 to 0.008 inch initial clearance.

5—Tight carbons stick in the boxes and the contact at the surface of the commutator is broken. This condition can be remedied by rubbing the sides of the carbons on sandpaper.

6—Broken carbons should be replaced.

Windings—

1—Wiring-around-frame leads to brushholders, if broken or loose, so as to swing against the frame, should be repaired and securely fastened.

2—In connecting the leads to the commutator, it sometimes happens that the throw of the lead is either too great, or too short, which has the same effect as shifting the brushholders.

3—Short circuited main field coils produce a weak field, and result in poor commutation; this condition further has a damping effect on the field that opposes sudden field changes with same results.

4—A reversed main field coil produces a weak field and consequent poor commutation. Check the polarity and reconnect.

5—Field control motors, with coils that have a number of turns arranged to be cut out, have been known to be so connected that the weak field is used in place of the strong one. Check connections.

6—Where the field coil is encased in a metal box to make it water and fire-proof, this box acts as a damper, and opposes sudden field changes. Sometimes this is remedied by making a saw-cut in the box and filling the opening with a hard insulating material.

7—A short-circuited commutating pole-coil produces a weaker commutating field, which results in poorer commutation.

8—A reversed commutating-pole coil weakens the commutating field and results in poorer commutation. Check the polarity of the coils.

Operation—

1—Faulty control operation that allows sudden voltage changes at motor terminals can be remedied by checking the control circuit.

2—Rapid acceleration can be remedied by issuing instructions to the trainmen or by the use of an automotineer or automatic control.

3—Suddenly reversing the current through the motors to make a quick stop, commonly known as plugging the motors, tends to cause flashing. A campaign of education of the trainmen is the best remedy.

4—Heavy interurban service with a number of cars pulling on the line at the same time, sometimes causes sudden voltage changes, resulting in flashing. This condition might be helped somewhat by a rearrangement of the schedule.

5—Troubles caused by breaks in the third rail at crossovers and highways can best be reduced by passing over this special construction work with power off.

6—Where high-speed running (ordinarily down-grade) causes flashing, the trainmen should keep within a definite maximum speed.

7—If high trolley voltage (600 to 650) is used on motors designed for 500 volts, motor details must be kept in good condition.

8—When the motors are overworked and considerable heat and gas (from insulating compounds of newly repaired windings) is present inside of motor, these tend to prolong a flashover, and can be relieved by operating the motors with the commutator covers off.

9—Loose or worn bearings allow considerable vibration that tends to lift the carbons from the commutator, and cause flashing.

10—Rough track has the same effect as loose bearings.

11—Cars with flat wheels produce the same result as running over a rough track. Defective wheels should be made round by turning or grinding or by the use of an emery insert brake-shoe.

Electrically Heated Hot Moulding Presses

A branch of the industry in which the use of electrically generated heat is rapidly increasing is in the moulding of Bakelite and similar compositions. This moulding is done in presses such as that shown in Fig. 1. The platens of such presses must be heated. Until recently steam has been used almost exclusively for this purpose, though gas has also been used. When steam is used, the temperature of the platens is limited by the steam pressure. A case is recalled where a manufacturer experimented with a steam heated press to determine the temperature at which the best quality of moulded parts were produced. It was found that the higher the temperature was raised, the better was the quality of the finished product. The temperature was increased by increasing the steam pressure, which finally exceeded a safe pressure for the boiler. Since the quality of the moulded material continued to increase, it was decided to install an electric heating equipment whereby temperatures far in excess of those that could previously be obtained with steam could be secured without any danger of boiler explosions. Gas has also been used to heat platens but offers the usual objections, *viz.*, difficulty of

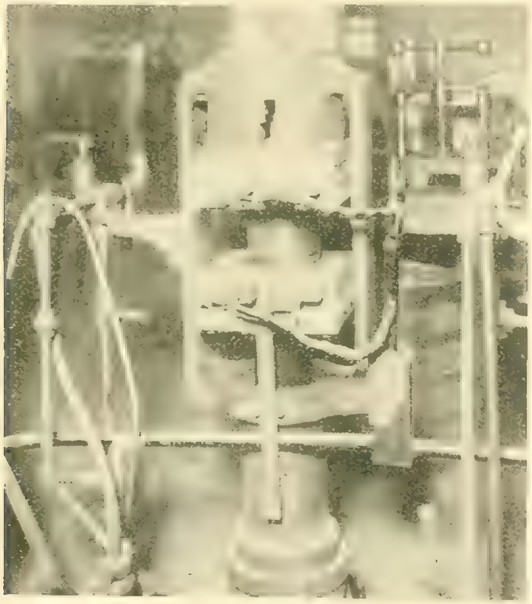


FIG. 1

confining the heat to the platen being heated, and unhealthy and disagreeable working conditions.

When it was first decided that electric heating should prove satisfactory for press heating applications, a trial installation was made which proved so satisfactory that the remainder of an equipment consisting of twenty-three presses was equipped with electric heaters.

The illustrations clearly show the manner in which hot moulding is done. A press consisting primarily of a suitable frame work supporting two or more platens is used for this purpose. One of the platens, usually the upper one, is stationary and the others are capable of movement usually vertically in guides, though in some cases the movement may be in other directions. Fig. 1 shows a twenty ton hydraulic press with two platens, the upper one of which is stationary while the lower one can be raised or lowered vertically. Each platen consists of two rectangular steel plates 12 by 12 by 1.75 inch, in which grooves are machined to receive the heaters, which are of the same type as those used for heating the warming table described in the June 1918 number. The heaters are the same length as the platens, four heaters being clamped between the two plates of each platen by suitable screws. The exposed surfaces, other than the working surfaces, are covered with thermal insulation to reduce the heat losses from the platens. The platens are separated from the heads of the press by asbestos lumber plates to decrease the amount of heat conducted away.

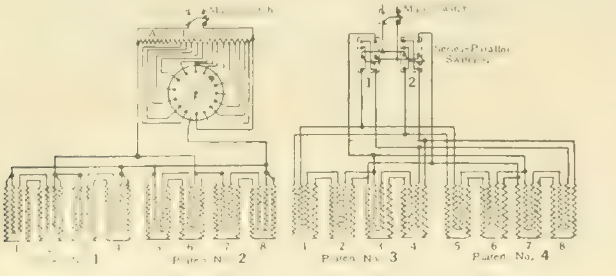
FIG. 2

The electrical input it is necessary to provide for a press depends on the size of the platens, the working temperature, the initial temperature of the moulds, their size and the time required for heating them. The press described above is provided with heaters having a total maximum input of 2400 watts. This is sufficient for bringing the cold press up to operating temperature in one to one and a quarter hours while a reduced input of 1800 watts is sufficient for maintaining the platens at operating temperature when moulds weighing up to 30 pounds are heated, the operating temperature being 200 degrees C. The heating periods vary from twelve minutes for light moulds to thirty-five minutes for heavy moulds.

FIG. 3

As indicated above, some means for regulating the input of the heaters is required. The installation described is provided with an autotransformer, taps from which are brought out to contacts on a dial. A number of different voltages are thus supplied, any one of which can be impressed across the

heaters by moving a contact arm over the stationary contacts on the dial. Fifteen voltages varying from the line voltage of 220 to a minimum of 150 volts are available, the corresponding inputs varying from 2400 watts maximum to 1200 watts minimum. It is thus seen that this method of control is especially suitable where close regulation of input is required. Where



(a) (b)

FIG. 4

the class of work being done on a number of presses is the same, a single autotransformer of suitable capacity can be used to control several presses.

An alternative method of temperature control is the series-parallel system. This control is suitable where there is not such diversity of moulding being done and a number of operating temperatures at close intervals is not required. It consists of the use of two series-parallel knife switches. A diagram of connections for (a), the autotransformer and (b) series-parallel systems is given in Fig. 4, and Table I shows the input in percent of the maximum obtainable that can be obtained with any position of the switches, though these values depend on the design of the heaters. In all cases uniform distribution of heat over the surfaces of the platens is secured.

TABLE I—PERCENT INPUT OF HEATERS

Position of Switches		Watts Input in Percent of Maximum
Switch No. 1	Switch No. 2	
Up	Up	100
Up	Down	75
Up	Open	67
Down	Up	50
Open	Up	33
Down	Down	25
Down	Open	17
Open	Down	8

Among the advantages that can be mentioned from the use of electrically-heated presses are:—uniformity of temperature, constant temperatures, higher temperatures, close temperature regulation and absence of dirt, moisture and fumes.

R. A. Bolze

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest, information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A personal reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1620 Testing Large Alternator Armature—It was required to test a large armature after winding and cross-connecting. Accordingly the standard set-up was made as in Fig. (a). The test voltage was supplied from a regulator testing set through an auxiliary transformer of 25 kw capacity. Each phase was tested to core, the other two being grounded to the core. The gaps were set to arc over slightly above the proper test voltage and checked with the voltmeter, arcing over at K73. Next the armature was connected and voltage brought up. The gaps arced over at K64. The regulator was run down and test was completed by holding a voltage of K62 on the phases for one minute. Criticism was made that the gaps should not be allowed to arc over since it would put unfair strains on the armature insulation. How then are we to measure the one minute test voltage? The question is suggested by an analysis of the above observed phenomenon. The armature capacity distorted the voltage wave and test transformer ratio to such a degree that the gaps arced over at K64 about 12.5 percent lower than without the armature in circuit. Therefore if we had set the gaps 20 percent high and brought the test voltage up to approximately K73, we should have had a crest voltage corresponding to K83.5 r.m.s. (73/64 = 83.5/73) which crest voltage would have imposed a much more severe test than required and one likely to seriously strain or break down the armature. This is a very important matter and one the standardization rules cover vaguely. I should like to hear how others carry out this class of tests.

C.W.B. (MICH.)

We assume that K73 etc. are voltmeter readings. The practice followed in most cases is as you have outlined. It has been followed for many years in commercial test departments. While there is some risk of producing a short-circuit in the windings due to high frequency effects from the arcing gap, a

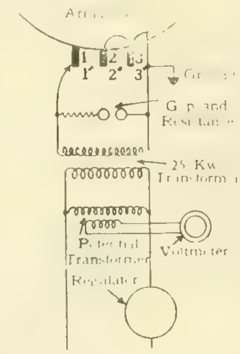


FIG. 1620 (a)

careful operator can generally avoid damaging the windings. It is necessary to use a light fuse or to adjust the circuit breaker so that the arcing will not be prolonged. In addition, the resistance specified by the A.I.E.E. will limit the current to a value where high frequency effects are not likely to do harm. It would be better to use a resistance of about 100 ohms per volt of test voltage rather than one ohm as specified by the A.I.E.E. This is the practice of commercial test departments and is much safer. Checks show that such a resistance produces no error in determining the proper voltmeter reading for obtaining the proper test voltage.

J.E.M.

1621 Transmission Power Factor—In Fig. (a), *A*, *B* and *C*, are generating stations having *X* as the center of gravity for their load. The normal power-factor of the system is 85 percent lagging. Would it help either *B* or *C* for *A* to carry 85 percent leading current?

C.A.A. (MINN.)

The power-factor of a single alternating-current generating station is fixed by the nature of the load which the station supplies. For instance, a load of induction motors will have a power-factor of about 80 percent. Induction motors combined with lighting will run from 80 to 90 percent power-factor, and combined with synchronous motors and synchronous converters up to 95 percent. It is impossible to change the

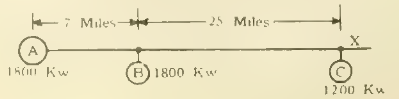


FIG. 1621 (a)

power-factor of the station by any adjustment within the power station, as it depends only upon the nature of the load. However, where there are generating stations in parallel, although the combined power-factor of the system is fixed by the nature of the load, the power-factor of each individual station depends upon the field excitation. If, in any station, the machines are over-excited, that station will carry more of the reactive lagging current of the system. In the example given, if the field excitations of the machines in station *A* are increased, that station will take more of the lagging reactive current, and its power-factor will decrease. On the other hand, if the excitation of the machines in stations *B* and *C* is increased sufficiently station *A* may be made to have a leading power-factor. The best method of operating in the

case given would be to over-excite station *C* letting it supply the bulk of the reactive lagging current required. In this way the line losses due to reactive current flowing along the line from stations *A* and *B* will be minimized. H.W.S.

1622—ACTION OF COMPOUND GENERATOR—Please explain the following behavior of the terminal voltage of a compound direct-current generator which was observed during the adjustment of a shunt for the series field in order to give a certain compounding. The compounding desired in this case was 236 volts no load, 250 volts full load. The generator was of 25 kw capacity. The procedure was first to put full load on the generator at 250 volts with no current shunted from the series field. Then the load was thrown off and the shunt field adjusted to give the correct no-load voltage. When the full load was put back on, the terminal voltage was of course too high, so current was shunted from the series field until the terminal voltage was 250 at full load. Now when the load was thrown off by tripping the circuit breaker the terminal voltage did not fall to 236 but to several volts above it. The shunt field was again adjusted to give the correct no-load voltage and the process repeated. Even after adjustments had been made so that the terminal voltage would rise from 236 to exactly 250 when the full load was thrown on, it would not fall quite to 236 when the load was taken off. After the load had been thrown on and off several times and adjustments made each time, a permanent condition was finally reached which gave 236 volts no load and 250 volts full load every time. Referring to Fig. (a), I assume the machine to be operating at 236 volts no load (*A* on the magnetization curve) assuming also that the condition has been reached so that the terminal voltage rises to 250 volts when full load is thrown on (point *B*), cannot the slightly high voltage (point *C*) when the load is taken off again be explained as the effect of hysteresis? Does the permanent condition giving correct voltage at no load and full load mean that we have found by trial a closed hysteresis loop with *A* and *B* as its upper and lower points? In Fig. (a) the dotted lines are meant to represent such a loop. Suppose the residual magnetism of the machine were changed. Would the same shunt on the series field give the correct compounding exactly when the machine was put into operation again? Also please explain by means of hysteresis, why a direct-current generator operating at normal voltage at no load builds up to a much lower value when the shunt field is opened and closed again. Why is this so much more noticeable on small machines than on large ones? C.A.A. (PA.)

This question calls up so many variables that a brief explanation is very difficult. In treating it, the conditions that exist from the beginning of the test to the end have been tabulated as outlined in the question.

First Condition:—(a) Shunt line crosses no-load saturation curve at *1a*. This makes no-load operating point 228.5 volts. (b) With this position of shunt line, full load volts rise to 250 with full series in as shown at *1b*. (c) This means that a portion of the pole face is worked at high induction—say at *1c*. (d) When load is thrown off flux decreases along a new curve *A*, due to hysteresis. The new low point of operation will be *1d*, 2.25 volts higher than the original starting point *1a*.

Second Condition:—(a) Shunt line is adjusted to give 236 volts as shown by

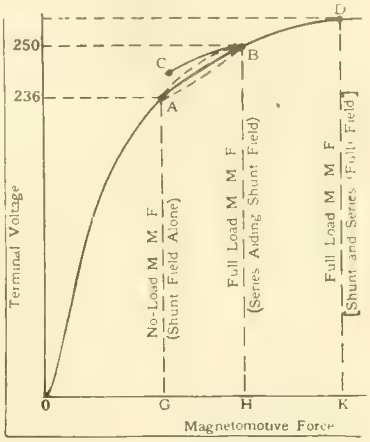


FIG. 1622(a)

crossing the no-load saturation curve at *2a*. The exact location of this point is a little to the right of curve *A*, since it is on the upward curve of a hysteresis loop having *A* for its downward curve. (b) Again full series is left in, while full load is put on the machine and this time the full-load volts rise to 252.75 as shown at *2b*. This is due to the increase in total exciting ampere-turns because of the new position of the shunt line as shown by *2*. (c) It is clear that the same portion of the pole face which was worked at high induction under (c) of the first condition is worked at a still higher induction now which may be indicated by point *2c*. (d) When the load is thrown off this time the flux decreases along another curve indicated by *B* for the same reason as given under (d) of the first condition. The new low point of operation will be *2d*, 1.75 volts above the 236 no-load volts. In this cycle of operation when the shunt is adjusted on series coil to give 250 volts

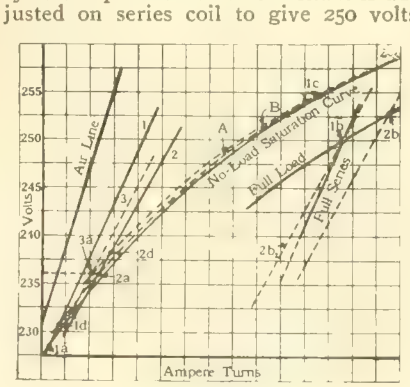


FIG. 1622(b)

(see series line $2b_1$) this operation is nothing more than a step in the reduction of flux along line *B* as mentioned above. The effect of miniature hysteresis loops caused by small variations of series ampere-turns while the shunt is being adjusted for 250 volts may be neglected. The new adjustment of the shunt field is shown by line *3* and the new 236 volt starting point by *3a*. As to the failure of voltage to fall to 236 volts after the no-load to full-load adjustment of 236/250 was made, this may be explained by the operators usual action of cutting in a large amount of resistance in the shunt field and then bringing the voltage back up to 236 before another no-load trial. The "permanent condition" spoken of in all probability was obtained by increment adjustment of shunt field at no-load and of series shunt at full-load. It is true that the hysteresis loop is closed, but the statement means nothing since all hysteresis loops are closed. The difficulty encountered is that the machine does not always operate on the same loop in going from no-load to full-load and back again. It is the variations in size of these loops that cause all the trouble and worry in obtaining fine adjustments in compounding generators. The size of the hysteresis loop on which a generator is operating determines the residual magnetism of the machine at that time; therefore, we may expect it to change when the hysteresis loop is changed. The above properties of a generator give the man on the test floor opportunity to meet refinements in specifications by holding his machine as high on the loop as possible while making the no-load adjustment. The reason why a generator builds up to a lower voltage after the shunt field is "flashed" (opened slowly and closed) is because part of the residual is destroyed by the oscillating current and also because the operating point is shifted from the upper curve to the lower curve of the hysteresis loop in case the no-load point had been approached and arrived at from the load condition. This is more noticeable in small machines because they have smaller air-gaps than are usual in larger machines. E.M.C.

1623—DETERIORATION OF WEATHERPROOF INSULATED WIRE—(a) Does insulated copper wire strung on pole lines deteriorate with time to such an extent that its insulation becomes impaired so that it could not be moved to another pole line and remain safe for voltages up to 2200? (b) Does the copper itself change its characteristics from soft drawn to crystalline, thus becoming weak and liable to break under the weight of ice and the force of the wind? (c) Is there any reason why No. 0 insulated copper wire which has been in service for 20 years on a pole line at 2200 volts with poles spaced 80 ft. apart should not be reinstalled on appropriate insulation, cross arms, and poles on 100 foot centers for use at 22000 volts? C.E.A. (MASS.)

(a) Yes. Any weatherproof wire removed from existing line should be carefully examined before re-installing. If impregnating compounds have been driven out, it is better to remove the insulation and use where bare wire is permissible. (b) If the copper conductor is not stressed above its elastic limit, its physical structure remains unchanged and its mechanical strength is not affected. (c) While it is standard practice to use weatherproof wire on 2200 volt overhead lines, this is only for limiting the short-circuits, due to an accidental cross or ground. Although weatherproof wire is an imperfect insulator, and the normal insulation of the line is maintained by the insulators alone, yet it serves to eliminate the

greater proportion of short-circuits which would occur, due to momentary contact, if bare wires were used. On higher voltage lines and certainly for 10 000 volts and over, bare wire is used to avoid giving a false sense of security. Therefore from this point of view, it would be satisfactory to use 2200 volt weatherproof cable on a 22 000 volt circuit since no insulation is required. It is of course understood that suitable 22 000 volt insulators will be used and the spacing of the wires increased considerably over the spacing of the 2200 volt cables. H.W.S.

1624—Changing Motor to Generator—Would it be possible to change any standard three-phase, 60 cycle, 110 volt induction motor to a three-phase, 60 cycle, 110 volt generator, by using rotary field coils supplied by an exciting current in place of the regular squirrel cage rotor? J.H.H. (VT.)

There should be no particular difficulty encountered in changing an induction motor to a salient pole synchronous generator as outlined above, provided the construction of the machine is such that the necessary mechanical changes can be made. On an induction motor, it is necessary to have a small air-gap and work at a comparatively low gap density in order to keep the exciting current low and hence have the power-factor as high as possible. Now since the same voltage and frequency is wanted on the synchronous generator it will be necessary to work it at approximately the same gap density as the induction motor. Although an induction motor has a large number of slots to minimize the reactance, they are usually partially closed, which gives a comparatively high slot reactance, compared to a synchronous machine, which has open slots. Therefore, with the high slot reactance and low gap density, the synchronous generator will have a high percentage reactance. This high reactance together with the low gap density, will tend to give a low short-circuit ratio (*i.e.*, the ratio of the field ampere-turns at no load to the field ampere-turns required to force full-load current through the armature windings on short-circuit) and hence poor voltage regulation. It will then be necessary to make the air-gap larger so as to increase the short-circuit ratio and improve the regulation. The maximum ampere-turns that can be put on the field may limit or fix the air-gap before a desirable short-circuit ratio is obtained, especially if the machine is to operate at a low power-factor. Although, as indicated from the above analysis, the synchronous generator will not have the most economical design proportions, it should operate satisfactorily under normal conditions. It may not be possible to obtain the same k.v.a. rating out of the generator as the induction motor, depending on how liberally the latter was designed. The greatest problem will probably be in designing the new rotating parts to fit the present mechanical construction of the induction motor. M.W.S.

1625—Meter Constant—I would like to get some information in regards to a Westinghouse type C, polyphase, five amperes, 100 volt, watt-hour meter, which is installed on a three-phase line with potential transformers 22 000 to 110 volts. Current transformers ten to five amperes. The above meter has been tested as a five ampere, 110 volt, single-phase meter with the current coils in series and the potential coils in multiple and run revolution to revolution with a Westinghouse standard using the five amperes, 110 volt coils. Standard $K = 0.333$. Would the K of the polyphase meter tested this way be 0.333 or 0.666? After the above meter was tested, a five ampere, 110 volt type OA meter was run with it. The dial reading of the type C was double the reading of the OA. The OA meter is single-phase. What would be the correct multiplier for the dial reading of the type C when calibrated this way and installed with the above transformer? B.B.B. (OHIO)

(a) The K (K_h or watthour constant) of the polyphase meter would be 0.666. This constant is the value of the electrical energy registered per revolution of the disk and is expressed in watt-hours. (b) If the polyphase meter is equipped with a one kw gear train the multiplier would be 400. T.S.P.

1626—Changing a Three-Phase Generator to a Synchronous Motor—I have a 100 k.v.a., three-phase generator which I would like to convert into a synchronous motor; this machine is of the revolving field type. Will it be necessary for me to start it with an induction motor or can I apply the current to the stator through a compensator or autotransformer? Will it be necessary to shunt the field winding through a resistance to minimize the induced voltage while starting? R.H.L. (BRIT. COL.)

The generator will probably operate satisfactorily as a synchronous motor under normal conditions. However, if the rotor is not equipped with a damper winding, the machine may not be self-starting, and it will then be necessary to bring the machine up to speed by some external means, as an induction motor. On some small machines of this size without damper windings, where the poles are not laminated, it is sometimes possible to start them by the application of reduced voltage to the stator windings. Instead of currents being induced in damper bars, as in the case of machines with damper windings, eddy currents are induced in the pole faces, which produce sufficient torque to bring the machine up to speed. This method of starting, depending on solid poles is uncertain. Even if the machine is brought up to speed by external means, it may not operate with satisfactory stability if the voltage of the system is not well-balanced, or if the load is fluctuating. If the machine is started by external means, it will not be necessary to shunt the field with a resistance, as there will be no induced voltage in the field windings. However, if the machine is to be self-starting, the field circuit should be closed through a resistance to absorb the induced voltage in the field windings. This resistance should be about the same as that required to give normal voltage on the generator with normal exciting voltage. M.W.S.

1627—Testing Galvanized Iron—Kindly furnish me with information on the Preece method of testing galvanized iron. H.S.R. (MASS.)

The Preece or "bluestone" test for galvanized iron is made as follows:—The samples before testing must be thoroughly clean and free from oil. The testing solution is prepared by saturating distilled water with copper sulphate and adding a little cupric oxide to neutralize any free acid present. This mixture should stand 24 hours before using, in a glass or earthenware vessel. The solution is then poured off or filtered clear, and is diluted with distilled water to a specific gravity of 1.186 at 18 degrees C. (65 degrees F.). The samples should be tested in a glass or earthenware jar containing enough solution to cover the sample. A new solution is used for each test. In making the tests, the sample is immersed in the solution, which is kept between 16 and 18 degrees C. (62 and 65 degrees F.), for a period of one minute. The sample is then removed, rinsed in clean water, wiped dry with soft waste, and immersed again for a period of one minute. The number of one-minute immersions required to produce a bright copper-colored deposit upon the sample determines the excellence of the coating. A minimum of four one-minute immersions or "dips" is considered satisfactory. This test gives an excellent idea of the quality of hot and cold galvanized coatings and is also used for testing sherardizing, although it is not a very satisfactory test for the latter. L.M.

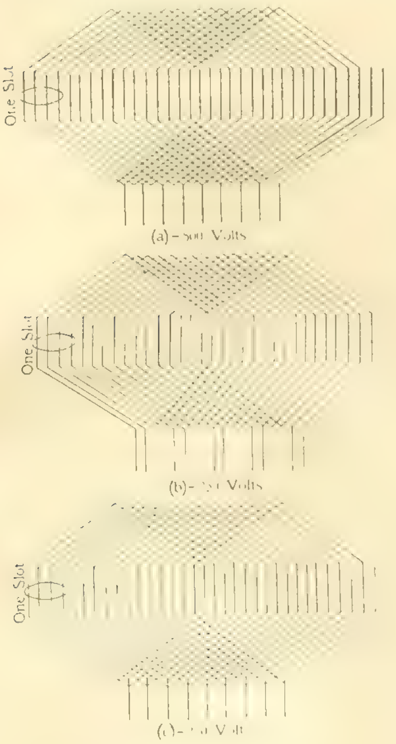
1628—Emulsified Oil—In the oiling system of a turbine which also supplies pressure to the hydraulic governor, do you think that the presence of water in the oil, forming an emulsion with it, could render the governor inoperative? In our forced-feed oiling system supplying engine oil to our engines, we have observed that the presence of water in the oil causes the cups to stop feeding and it is then difficult to get either oil or water to come through. The pressure is 50 lbs. F.H.W. (COL.)

The oil operating mechanism of a hydraulically-operated turbine governing device would very likely have all of the oil passages sufficiently large so that the presence of water or emulsion would have no effect on the operation of the valves or on the accuracy of the governing. In a forced-feed oiling system for reciprocating engines the pipes themselves are quite small and the openings through the oilers exceedingly small. Consequently any liquid that is less free-flowing than oil will restrict or entirely stop the flow through them. J.F.J.

1629—Direct-Current Armature Winding—Please discuss which of the following changes of a six-pole armature connection from 550 to 275 volts should give the best operating results. Also any faults or advantages of either method. The armature has a strap winding of 195 slots 8 conductors each, forming 390 coils 2 turns each, with 390 commutator bars and risers. Connections are single parallel as shown in Fig. (a). The following changes would be made to connect as shown in Fig. (b). Raise all top leads and move into connection with bottom lead laying fourth to right, thus placing the two ends of same coil in commutator riser adjacent but one, or forming a two-circuit parallel winding of 195 coils 2 turns each per circuit, also using 2 commutator bars and risers

in multiple. Should the two circuits be connected at each pair of risers, or at regular intervals, such as fifth pair or depend on the brushes to parallel them? The other method proposed would necessitate the changes shown in Fig. (c). Remove connecting clips between risers and use 2 conductors as one, thus forming a single parallel winding of 390 coils one turn each and using a single riser and bar to carry and commutate twice the original amperage. W.I.S. (TENN.)

Either of the schemes proposed for reconnecting the 500 volt armature for 250 volts is possible. Fig. (b) is preferable as it gives the smaller number of parallel paths and one turn per coil, the best combination for commutation. If Fig. (a) is used, the two circuits should be connected at each pair of



FIGS. 1629 (a), (b) and (c)

risers. This will give the effect of a single parallel winding of 195 bars. In either case it probably will be necessary to increase the brush size somewhat if the current-carrying capacity of the machine is to be increased. In order to avoid commutation troubles an increase in brush width should be avoided. It will probably be possible to work the brush at a higher current density than is now used, but the density should not exceed 50 amperes per square inch and the width of brushes should not be increased more than is necessary. R.W.O.

1630—BRAKE-WHEEL DIAMETER—In the May 1918 issue of the JOURNAL, p. 173, there is a curve showing the best diameter of brake wheel for a given torque. Am I right in understanding that this curve shows the torque capacity of a brake wheel of given diameter with a face one inch wide? G.K.M. (MD.)

The wheel diameters used in making up the curve shown on p. 173 are obtained from eq. (18) on p. 174 for a number of values of torque and these diameters are plotted as ordinates against the corresponding values of torque. Eq. (18) contains a constant C_1, the value of which is given in Eq. (19). This last equation contains the factor C_2 which is the ratio of the face width of the wheel to its radius. Therefore, the wheel of a brake for a given torque capacity will have a wheel of the diameter given by a curve and a width equal to C_2 times the radius. The curve in Fig. 7 is made up from a line of brakes in which the shoe width is 0.7 times the radius. The torque capacity of a brake wheel depends upon the shape of the shoe, the pressure per square inch on the shoe, and the coefficient of friction between the wheel and the shoe. As these factors are more or less fixed by the materials used and the general design, it follows that for a given torque the diameter of the wheel will depend upon the value of C_2. The brake wheel with a small diameter and a wide face will have less stored energy when running at a given speed than the wheel of large diameter. In general, the diameter of the wheel will be limited by the dimensions of the motor with which the brake is to be used to such a value that the stored energy of the brake wheel will be a small percentage of the stored energy of the motor armature and the driven load. On the other hand the brake with a large wheel diameter will not require as large a magnet to release the shoes as a brake with a small wheel diameter. F.M.B.

1631—BOOSTER TRANSFORMER—Is it possible to use one single-phase transformer as a booster on a three-phase circuit? If so, please give diagram of connections. J.G.C. (MD.)

One single phase transformer cannot be used as a booster in a three-phase circuit. W.M.M.

1632—POLYPHASE NOTATION—In the article entitled "Notation for Polyphase Circuits" in the Sept. 1907 issue of the JOURNAL, p. 499, occurs the phrase "If $E_{AB} = E \sin (pt + \theta)$ then $E_{AO} = E \sin (pt + \theta - 120°)$ and $E_{OA} = E \sin (pt + \theta - 240°)$." Please explain the meaning of θ and $(pt + \theta)$. E.M. (N.Y.)

The more usual notation is $E_{AB} = E \sin (\omega t + \theta)$ in which ω (p in Mr. Porter's article) equals the angular velocity of vector rotation equals 2π times the frequency in cycles per second and t represents time in seconds. The expression ωt (or pt) thus defines the location of the vectors at any particular instant. θ (the lower case letter is usually used although in Porter's article the capital letter H is used) represents the angle of lag or lead (depending on the sign) relative to the position indicated by ωt. C.R.R.

1633—ILLUMINATION DATA—Kindly give me information in regards to the following lighting distribution formula:—

$$\text{Lumens} = \frac{\text{Area (Sq.Ft.)} \times \text{Intensity (Foot-Candles)}}{\text{Constant}}$$

Will you kindly explain where the height of the lamp above the floor is taken into account in this formula. In tables given, the same constant is used on any height of ceiling. J.H.H. (ALA.)

This formula, which is commonly used in the flux of light method of calculation, is entirely independent of the number of lamps and of the ceiling height. The constant in the denominator is usually described as the "coefficient of utilization" and is dependent upon the kind of reflector used and the nature of the surrounding walls and ceiling. In its more complete form this equation includes also a depreciation factor by which the numerator is multiplied, having a value from 1.2 to 1.4 which takes into consideration the fact that an old and dirty lamp does not give as much light as a new one. Having determined the total number of lumens required to light a given area by this formula, the number of lumens per outlet, or in other words the size of lamp to be used is determined by the lamp spacing desired, which to a certain extent is dependent in turn on the height of the ceiling and the size of lamps available. Having determined the size of lamps and spacing, the height of the ceiling or the mounting height determines the type of reflector. Thus a relatively low ceiling would require an extensive type of reflector; a very high ceiling, relatively, would require a concentrating reflector while a moderate ceiling would require an intensive or focusing type of reflector. The flux of light method assumes that with suitable reflectors the same amount of light will be produced on the working plane per lumen, regardless of the height of the ceiling. C.R.R.

1634—FREQUENCY CHANGER SETS—I have four belt-driven frequency changer sets changing frequency from 60 to 90, 440 volts going in and 473 volts given out on the rings. (a) Will it be practical to parallel these machines and would they be synchronized the same as generators? I also have several motors which I think are overloaded. Please advise me the simplest way to find out the overload these machines are pulling. (b) I have an ammeter and a voltmeter but no power-factor meter, but wish to know the power-factor. F.A.L. (VA.)

(a) The belt-driven frequency changers apparently consist of induction motors driven in reverse direction so as to obtain a frequency of 90 cycles in the wound secondary. These machines may be operated in parallel and will have to be synchronized just as in paralleling any ordinary alternating-current generators. If the four machines are belted to separate engines synchronizing will be easily accomplished, but if they are all driven from the same line shaft some difficulty may be encountered unless there is some ready means of bringing the separate machines into phase. The speeds of all of them will be the same (assuming equal pulley ratios) but the phase positions might be different. The only way to bring the voltages of any two machines into phase, if they were too far out of phase to be safely paralleled, would be to cause more belt slippage on one machine than on the other. If one of the belts were run over an idler pulley which could be adjusted to give any desired belt tension the slippage could be made sufficient to bring the two voltages into phase. Some method of adjusting belt tension is desirable from the standpoint of load division also since the proportion of the total load which each machine will carry, when the four are in parallel, depends upon the tension of its belt. (b) In order to find the power-

factor of an induction motor it is necessary to know the kilowatt input as well as the voltage and current. If a wattmeter is available, so that the kw input can be measured, the power-factor may be found from the formula:—

$$\textit{Power-factor} = \frac{Kw \times 1000}{Volts \times Amps \times C}$$

Where C is 1.73 for a three-phase, 2.0 for a two-phase or 1.0 for a single-phase motor. The horse-power delivered by the motor may be found approximately as follows:—

$$\textit{Horse-power} = \frac{Kw \times 0.9}{0.746}$$

If a wattmeter is not available the power-factor and horse-power output can probably be obtained from the manufacturer provided he is given a reading of current and voltage under maximum load conditions and the serial number of the motor. Q.C.

1635—Rewinding Induction Motor—We have a 440 volt, three-phase, 60 cycle motor which we want to change to two-phase, 220 volts, 60 cycles. *A* says the nearest it can be connected to 220 volts is 240 volts which will be a ten circuit connection one group of six coils each to a circuit. *B* says this makes a 165 volt machine. Now which is correct? Also is there a better way to reconnect this machine? The present connections are five circuit star, two groups of four coils each to a circuit. There are 120 coils in this stator. F.S. (N.J.)

In general a two-phase winding requires 1.25 times as many total turns for the same voltage as the corresponding three-phase or expressing it in voltage, whenever a three-phase motor is reconnected for two-phase it should be operated on 80 percent of the three-phase rated voltage. In the case given if the winding were connected 10 circuit star it would be good for 220 volts, three-phase, or if it were connected two-phase, 10 circuit it would be good for 176 volts, two phase and not 240 as stated. Hence *B* is more nearly correct. In all cases of changing from two to three-phase or vice versa, attention should be given to the question of "phase insulation" between the pole phase groups. This is discussed in an article on "Reconnecting Induction Motors" by Mr. A. M. Dudley in *The Electric Journal* for Feb. 1916. A.M.D.

1636—Tirrill Regulator—Referring to instruction book No. 85502 B under the title of "Voltage Regulators for Alternating-Current Generators," Type T A, forms F and K, issued by General Electric Co., pages 20, 21, 22 and 23, paragraph headed "exciter field rheostat and generator field rheostat adjustment." In the plant I am employed we are using a G. E. Tirrill regulator and up to the present time have not adjusted the rheostats for the operating points (to be used when regulator is in operation). Electricians claim that it is almost impossible to make the time adjustment on the exciter rheostat and have decided that it is not necessary anyhow. We simply turn the exciter rheostat to some point where good parallel operation of exciters is obtained and adjust generator rheostat until proper generator voltage without cross currents is secured. The question is why is it necessary that instructions be followed as to rheostat adjustment and what is to be gained by making these adjustments. Personally, I find that these points would come mighty handy many times, especially when cutting in another exciter or generator but the convenience argument does not seem to interest them enough to make the adjustment. I wish to be able to show that a more stable operaion of both exciters and generators will be obtained and that there will be less arcing at the relay contacts. E.M. (N.Y.)

It is necessary to give some definite instructions for the setting of exciter field rheostats so that it will not be necessary to take up each individual case for installation. It was found after experiments on different exciters that universal satisfaction was obtained from the adjustments described in the instruction book. In some cases it is not necessary to turn in as much resistance in the exciter field circuit as in others but these are exceptions rather than the rule. The reason for the adjustment as outlined in the instruction book are due to some exciters being more sluggish to respond to field excitation than others, as for instance a quick operating exciter would require less field resistance than a slow operating exciter. H.A.L.

CORRECTION

In the July 1918 issue, at the bottom of p. 261, left column, the negative sign was omitted from 147, 150, 372; also from 18665 near the middle of the right column.

In the first line under Fig. 8, p. 261, the expression $1/n \ tan^{-1} B_n A_n$ should read $1/n \ tan^{-1} B_n/A_n$

THE ELECTRIC JOURNAL

VOL. XV SEPTEMBER, 1918 NO. 9

The Association of Iron and Steel Electrical Engineers

The Association of Iron & Steel Electrical Engineers will hold their twelfth annual convention, September 11—14 at the Southern Hotel, Baltimore. The attendance at these annual meetings is made up of members and guests from all parts of the country to discuss problems pertaining to the electrical equipment for steel mills or such equipment to make a complete installation or unit.

At the present time, the association has 250 active, 460 associate and 32 firm members who are identified in some way with the iron and steel industry or in the manufacture of electrical equipment to be used in actual production and finishing steel products. Under the present war conditions the iron and steel plants have been called on to do their utmost. This in turn has made new and additional problems for the electrical engineer. The object of the Association is the advancement of the application of electricity to the iron and steel, or allied industries by the co-operation of its members. In reviewing the past ten years it can plainly be seen that the object is being carried out and much credit is due the Association and its members. The Association stands ready to give any assistance possible when called upon.

The Philadelphia Section, under Mr. R. F. Gale as chairman and Mr. L. O. Morrow as secretary, has done wonderful work. Their monthly meetings have been well attended and the papers presented have been of high class and freely discussed. They have also added many new members, which shows their loyalty in the affairs of the Association.

The Cleveland Section under Mr. L. W. Egan as chairman has been holding regular meetings each month and, as their territory is limited, they are doing their best with gratifying results.

Chicago Section, being located at a distance, has been working at a disadvantage but has done good work for the Association.

Pittsburgh Section, located as it is in the midst of the big steel mills, has been quite active, holding monthly meetings and the papers presented have been in keeping with the policy of the Association.

Year by year our Association has grown in numbers and effective organization. We have many valuable members "Over There" doing their part in this world war, and we know they are doing their best. The Association has been quite active in Standardization Work. The Committee in charge, with Mr. W. T. Snyder, as chairman, has made very considerable progress along this line. It is only necessary to read the Annual Proceedings for the past two years to show what has been accomplished. The Editing Committee, Mr. E. Friedlander Chairman, has just completed the Annual Proceedings for the year 1917, making a volume of 775 pages.

An important step in Association development during the year, has been the appointment of Mr. John F. Kelly as permanent secretary, with headquarters in the Empire Building, Pittsburgh. Mr. Kelly has had a years' experience as secretary under the annual elective method in addition to extended experience in the steel business, having resigned from the electrical department of the National Tube Company to accept his new position, where he will be ready at all times to give any information pertaining to the affairs of the Association.

CHAS. A. MENK.

Electricity and the War

The use of electricity has become such a part of our daily life that we do not appreciate how differently this war would be fought were it not for the tremendous development of the electrical art during the last 30 years. It is no exaggeration to say that the methods of warfare have been revolutionized by the use of electrical energy in one form or another. For hundreds of years, men fought with spears and axes. A great improvement was made with the introduction of bows and arrows, as it was then possible to destroy the enemy at a greater distance. The introduction of gun powder rendered obsolete to a great extent the weapons previously in use, but not completely, as is evidenced by the fact that the bayonet still remains one of the most effective instruments for obtaining a decision.

The evolution of methods and instruments of warfare has tended to increase the distance between the combatants although the final decision must often be obtained in hand to hand fighting where weapons little different from those of hundreds of years ago are used. As pointed out by Gen. Black in his address before the A. I. E. E. at Atlantic City, the only new characteristic of this war is the use of air craft.

What part does electricity play in modern warfare? While new weapons of offense and defense are rare, yet the part played by electricity in improving and making possible modern methods is of vital importance.

Consider one of the most important requirements of modern armies—communications. The telegraph and

telephone are of paramount importance and in this war they have been supplemented by wireless communication both telegraphic and telephonic, and the latter will undoubtedly become of greater value as it is developed. Armies extending over hundreds of miles could not be coordinated were it not for the various methods of electric communication. How uncertain communications were before electrical methods were developed is shown by the anxiety suffered by Wellington waiting for Blucher to make the pre-arranged attack on Napoleon's flank at Waterloo. Such a maneuver was then very difficult while to-day attacks on fronts of a hundred miles are coordinated and carried out with certainty.

The latest development and one of the novelties of the war, the tanks, would hardly be possible without the internal combustion engine, which is absolutely dependent upon electricity for its operation. The part played by the internal combustion engine in this war cannot be over-estimated. It is inconceivable that such a war could be carried on without it. Without airoplanes, tractors, trucks, etc., movements of such magnitude could not be carried out, and the use of such instruments is increasing daily. Verdun was saved by motor trucks. Without electricity, they would not be possible. Artillery depends greatly upon electrical methods for determining the position of the enemies' guns which, even when carefully hidden, can be located and destroyed.

Turning now to naval warfare, without wireless communications, the absolute blockade of German surface craft would be impossible. Without such a blockade, the problem of transportation of men and supplies across the Atlantic would be enormously increased. Unfortunately electricity is also a servant of the enemy as well as ourselves and without it the submarine would not be practicable. This weapon which has been used in such a cowardly and despicable manner by the enemy, would have no value but for the electric motors and storage batteries which enable it to approach its victim unseen. Electricity is, however, performing an important role in the destruction of such craft.

The modern warship has its effectiveness enormously increased by the use of electrical devices for the operation and controlling of the guns. It is no exaggeration to state that without such electrical devices a ship would be a certain victim for one of equal power with them.

Modern warfare is waged not only on the battlefield, but also in the factories and on the farms. Were it not for the development of the central generating station and the readily applicable electric motor, our problems of extending and creating munition works would be enormously increased, and in fact it is questionable if such rapid development as has taken place would be possible. The electric motor finds an ever-increasing field in our industries, from the production of the steel to the manufacture and transportation of the finished guns and shells upon which we must depend for victory. The work of the electrical engineer, which has placed America in the forefront in this field, has made possible such a rapid extension and development in the work of providing equipment for our armies, as to astonish our friends and confound our enemies. Little as we appreciated the value of our efforts in times of peace, they are now bearing fruit in the vital work of providing the weapons for the heroic armies that are carrying on the war for freedom. When history is written, those men who have given their lives to the development of the electrical art will have a place of honor and they may now feel that they have contributed in no small degree towards making this world fit to live in.

WILFRED SYKES

Obtaining Running Balance

The old-fashioned cut and try method of obtaining running balance of rotating machines has always been a source of worry to mechanics and to engineers. Usually each shop has developed some genius, possessed apparently with a sixth sense who is able, by the cut and try method, to secure some semblance of balance. However, it was always impossible to reduce this to a science, especially with very long rotating elements, or in the case of motor-generator sets having two separate armatures mounted on one shaft. In these cases the efforts to obtain a smooth running balance have often extended for days, or even weeks, accompanied by much "higher mathematics" regarding critical speeds.

The modern tendency toward very high speeds has magnified these difficulties and has frequently been a stumbling block to the designing engineer. Cases are frequently encountered in high speed reduction gears where it has almost been impossible to determine the source of vibration. The advent of the dynamic balancing machine, described in this issue by Mr. C. C. Brinton, has largely solved all of these difficulties, for the reason that it is now possible, by a direct and straightforward procedure, to determine the exact amount of metal to be removed from or added to any rotating element to put it in exact balance, as well as the exact locations where this change should be made. In this way the question of dynamic balance has been reduced to an exact science, instead of remaining a very mysterious and evasive problem, and apparently it has made it unnecessary to consider at all many of the higher mathematical complications of critical speeds and harmonics, which the engineer was formerly led to believe were necessary to be taken into account.

From the practical viewpoint of the manufacturer and the operating man the advent of this machine is indeed a blessing. C. W. JOHNSON

The Electric Furnace in the Steel Casting Industry

W. E. Moore*

THE ELECTRIC FURNACE is revolutionizing the steel foundry industries where castings of small and medium size are made. Commercially, electric steel in the foundry dates back only about five years. There had been some instances of its use in a small way to be sure, prior to that date, but by far the greatest advance of the art begins with the year 1917.

CRUCIBLE MELTING

The original method of producing steel for the foundry was by crucible melting. Such steel is of excellent quality when high grade stock is melted; furthermore it is fairly hot when it comes from the crucible. The temperature can be adjusted by holding longer in the furnace when necessary, but high heats are very destructive to crucibles. The "pots", which are graphite-clay crucibles, are quite small, holding usually 200 lbs. each, so that for the larger castings, several "heats" must be dumped into a "bull" ladle.

Each pot contains steel of slightly different analysis and when mixed produces more or less reaction commonly known as "boil" in the bull ladle, thus tending to make porous castings.

Due to the absorption of carbon from the crucible, it is difficult to make castings low enough in carbon to obtain the ductility desired for many purposes. Furthermore, the steel reduces the silica from the clay of the crucible, tending to run the silicon content of the product high. The overpowering objection to the crucible process is, however, the high cost of the product due to:—

a—High cost of pure melting stock, as no refining is practicable.

b—Very high labor cost on account of the small heats handled.

c—Crucible furnaces are notoriously extravagant in fuel consumption, frequently using three tons of coal per ton melted.

d—High cost of crucible renewals, often averaging two to four crucibles per ton melted at a cost of $9 to $11 each, or $18 to $44 per ton for crucible alone.

For these reasons, the crucible melting shop is rapidly going out of use for castings and also for tool steels.

OPEN HEARTH MELTING

The open hearth furnace, generally of the acid, sometimes basic type, next came into favor for foundry steel. Such furnaces are of moderate first cost, economical of fuel and capable of making fairly good foundry steel, either soft or hard. When properly constructed, they are economical of fuel, using 500 to 1000 lbs. of high-grade coal per ton of steel melted and making two to three heats per 24 hours. The open hearth is well adapted to very heavy castings where great fluidity of metal is not required, but for small castings it is not practicable to carry the heats high enough to run thin castings without a large percentage of loss.

The heats usually come in such large batches, 15 to 60 tons, that very costly ladles, cranes and buildings are required and the length of time required for pouring such quantities allows the temperature—already too low—to drop seriously, so that "skulling" of the ladle and loss by "cold shuts" and improperly run castings is high. With the acid furnace, generally used in foundries, high-grade melting stock must be used, as no refining is practicable.

THE SIDE-BLOW CONVERTER

During later years, the side-blow converter process has become very popular in steel foundries, making castings of medium and small size. In this process, high grade, high silicon, low phosphorous and sulphur pig iron is melted in a cupola furnace with the finest grade of coke obtainable. The quite hot liquid iron is then tapped into a ladle and transported and dumped into the converter. The converter is then tilted until the blast tuyeres which enter at the side of the vessel are turned down to blow directly onto the surface of the metal. The blast which is generally from a Root type blower is then turned on, impinging sharply against the surface of the metal, which is thus violently agitated and oxidized. The air blast burns out the silicon and then the carbon, the products of combustion being CO_2 and SiO_2, which combustion greatly increases the heat of the metal, as brought from the cupola. When the process has proceeded far enough, which the operators guess at from "the drop of the flame", the ferroalloys and a large "dose" of aluminum are thrown into the bath to reduce the oxides, neutralize the sulphur, and "kill" the steel, which would otherwise be "wild", e. g. full of effervescing gases, when poured. It would also be "hot short" that is prone to crack when freezing in the moulds, unless doctored by the addition of manganese as the converter effectively burns out the manganese of the pig iron charge. The steel is then dumped from the converter into a bull ladle in which it is transported by traveling crane directly to the larger moulds, or to be shanked off into the smaller moulds by small hand ladles.

The advantages are:—Converter steel may be made quite hot and fluid enough for quite thin castings; the heat, usually averaging two tons, is of convenient size to be poured off quickly. The fuel consumption is moderate, though rather higher than for the iron cupola, averaging 400 to 600 lbs. of coke per ton. The first cost of the apparatus is low.

The disadvantages are:—The metal must be handled twice in the ladle. The metal picks up sulphur and phosphorous from contact with the fuel in the cupola. The losses in the cupola and converter are quite high, running from 17 to 24 percent, further concentrating and increasing the percentages of impurities in the original metal and wasting costly melting stock.

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The steel is full of oxides and gases and requires large quantities of expensive ferro-alloys to "kill". The quality of the steel physically as well as chemically is below par. A heat once blown too cold cannot be brought up in heat enough to cast and must be "pigged."

Only the highest grades of melting stock may be used, costing generally $10 to $20 per ton more than for the acid open hearth furnace and $20 to $35 per ton more than for the electric furnace. The maintenance is high, as the cupola and concrete linings must be repaired after each 10 hours run.

THE ELECTRIC FURNACE

The electric furnace is the newest steel producing furnace and is gaining in popularity more rapidly than all others. It is the most compact furnace of them all and the rapidity with which it will melt down cold charges adapts it to the making of steel castings. It is the cleanest and most certain method of making specification steel. Its relative freedom from dust and dirt and its small bulk make it feasible to locate the furnace near the center of the floor where the metal need be transported short distances only. The size is small and convenient and the heats come rapidly, so that no large floor area must be tied up in moulds for each heat and it works to best advantage on the foundry floor.

The arc type furnace is most advantageous for foundry work and the most popular size has a capacity of three tons per heat. The more highly powered and rapid furnaces for such work turn out eight to twelve heats per twenty-four hours, and with a power consumption of 500 to 650 kilowatt-hours per ton of liquid steel, or considering the efficiency of the large modern turbogenerator power house at, say, 1.5 lbs. of coal per kw-hr., its fuel consumption might be said to be the equivalent to 750 to 900 lbs. of coal per ton, and the coal need not be of high grade, nor low in sulphur and phosphorous as is customary with fuel fired furnaces.

Since the charge is melted in a reducing atmosphere, there is practically no oxidization of the metal; consequently thin scrap or light fluffy turnings or scrap of other forms, such as can be conveniently charged into the furnace, may be melted. Such scrap on the present market sells for approximately $12 to $15 per ton less than "low phos.", heavy melting scrap necessary with the ordinary acid open hearth melting furnace installation.

The furnace atmosphere being of a reducing nature makes it easier to refine and kill the steel, resulting in a saving of frequently half of the ferro-alloys necessary with converter steel, effecting a saving of say $2.00 per ton. The melting losses in the electric furnace are much the lowest of any modern process, averaging one to five percent, as against six to nine percent in the open hearth and 16 to 24 percent in the converter process.

The electric furnace does not contaminate the metal as with fuel heated furnaces and will therefore readily make No. 3 U. S. A. specification steel, where it is nowdays practically impossible to find melting stock sufficiently pure to do so with the converter process. The saving alone in the cost of melting stock will more than pay the entire conversion cost of electric steel. The deader, more quiet steel yields a larger percentage of good castings and the lower sulphur renders the castings freer from shrinkage, flows and cracks, while the hotter, more fluid steel renders possible thinner weight and lighter sections than can be produced commercially by other processes. The greatest point in favor of the electric furnace is the much higher grade of castings produced.

With the electric furnace, the foundryman can more readily make and check his steel to exact percentage of carbon, manganese and silicon, and can easily keep the undesirable sulphur and phosphorous to low limits. The heat may be readily alloyed with nickel, chromium and vanadium to make the higher grades of steel castings for special purposes, such as may be required for parts of unusual strength, ductility or for cutting tools; it is thus entirely feasible to make castings which will run up to an ultimate of 130 000 lbs. per sq. in.

At the present time, foundry furnaces are usually run with acid linings, as purchasers are glad to get castings of any specification steel, but when the war is over and buyers become more discriminating, it is believed that much closer specifications will be issued and still better grade required, especially lower limits on sulphur and phosphorus. Then the basic lined electric furnace will become an everyday foundry necessity. Basic steel cannot be properly worked in a long arc furnace, furnaces using 55 volts at the arc during the refining period being the upper limit for heavy duty work, if reasonable life of the refractories is to be attained. For rapid work on refining, furnaces constructed so as to allow a large diameter shallow metal bath are essential. Every facility must be provided for readily slagging the furnace and all conveniences must be afforded for fettling and repairing the banks and bottom, which the highly corrosive slags cut away rapidly. The carbon or graphite electrodes oxidize slowly away and facilities must be provided for adjusting or renewal. The refractories flux down occasionally and must be replaced. It is a matter of vital importance that the furnace be provided with facilities whereby such adjustments and renewals may be made with minimum loss of time, production and labor, for the furnace is quite hot and repairs uncomfortable for the men to make, even with the best facilities.

By reason of the now generally acknowledged superior quality of the product, greater flexibility of operation, quicker, more convenient sized heats, saving in alloys and in cost of melting stock, the electric furnace is rapidly coming to the front in the steel foundry, wherever suitable power is available and progressive policies in vogue. It is making possible the profitable operation of widely distributed small steel foundries to an extent not generally realized.

Installation and Care of Large Electrical Apparatus for Steel Mills

O. Needham

STEEL MILL motors are practically always located so that they are subject to a large amount of dust and dirt, and the service which they are called upon to withstand is of the most severe character. The precautions discussed in this article apply particularly to the larger motors and their accessories such as those used to drive the main rolls in steel mills. In general the installation and care of this class of machinery is similar to that for other large electrical power apparatus, but on account of the exceptionally severe service and the unfavorable nature of the surroundings, certain features require particular emphasis.

INSULATION PROTECTION

Steel mill motors are given an insulation test before shipment of twice normal voltage plus 1000 volts in accordance with the A. I. E. E. rules, insuring an ample factor of safety against insulation break down, but this wide margin of safety is naturally reduced after the machines are in service. The rate of deterioration depends on several causes, the principal among which are excessive overloads, abnormal voltages, mechanical vibration, accumulation of dirt and sweating of the windings.

Overloads—Motors should be protected against injurious overloads by proper control apparatus.

Abnormal Voltages may be occasioned by partial grounds, lightning etc., and the insulation should be guarded against breakdowns due to this cause by suitable lightning arresters, reactors, and other standard devices.*

Vibration—Mechanical vibration is caused either by improper alignment, loose foundation bolts, unbalanced couplings or is transmitted to the motor from the mill equipment. Wherever possible, the motor should be protected from vibration from the mill by the use of a well-balanced flexible coupling.

Dust and Dirt—No doubt the most prolific source of trouble is the collection of dirt and dust in the windings. An analysis was made of a sample of dust taken from the bedplate of a rolling mill motor, the composition of which as follows:—

Water	2.2 percent
Carbon, as coke dust, etc.	16.6 percent
Silica (SiO_2) as slag, sand, etc.	9.8 percent
Iron oxide (Fe_3O_4) as scale and ore	63.0 percent
Aluminum oxide (Al_2O_3)	6.8 percent
Calcium oxide (CaO)	1.0 percent

Eighty-one percent of this deposit is good conducting material which would tend to introduce creepage. It is for this reason that greater precaution should be taken in steel mills, to protect electrical apparatus, than in other industries where the atmosphere is not laden to such an extent with conducting material.

Motor House—It is advisable to provide a motor house within the mill to protect the motor and control apparatus from mill dust and gas fumes which attack the insulation and corrode the brass and copper parts. Corrosion is very destructive to these parts, particularly to commutators, and works into connections not soldered, causing heating and creepage. When a motor room is provided, it is easier to keep the apparatus clean, the mill men and unauthorized persons are kept away from the electrical equipment.

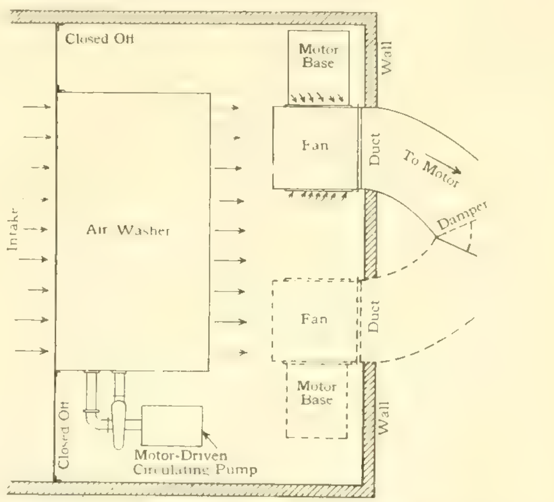

FIG. 1—LAYOUT OF VENTILATING SYSTEM FOR MILL MOTORS
This is the usual arrangement when two blowers are installed, one acting as a spare.

Ventilation—One of the most important things to consider in the installation of a motor room is to make certain that the air for ventilating purposes is taken from a clean source. In every case the motor room should be completely closed off from the mill and where clean air is not directly available, an air duct with a blower should be provided.

It is seldom possible to obtain clean air in a steel mill, so that these systems are usually provided with air washers. An arrangement of an air washer and two blowers is shown in Fig. 1, one of the blowers being installed to act as a spare. If the washer is placed between the blower and the motor, the former is subjected to the pressure of the blower, which has a tendency to cause leakage. For this reason, the air should always be drawn through the washer at atmospheric pressure. The amount of air necessary to ventilate a motor depends upon its electrical losses. It is best to have the manufacturer specify the amount of air necessary, but

*Various methods of protection against abnormal voltages are discussed in an article by Mr. P. M. Lincoln in this issue on p. 346.

as a general rule about eight cubic feet per rated horsepower per minute will be sufficient.

In laying out ventilating ducts, care should be taken to avoid sharp turns, as these seriously interfere with the passage of air. The ducts should be made as straight as possible and of such dimensions that excessive air velocities will not be encountered. Velocities in the duct of not over 2000 feet per minute have been found most satisfactory for this purpose. This applies to all passages from the source to the motor. The air in the washer, however, should not travel over 600 feet per minute, as otherwise moisture may be carried to the motor.

The air intake should be provided with two openings, one arranged to take air from the inside of the motor room and the other to take air from the outside of the building. This arrangement is necessary, since in the winter,the air which is taken from the outside will carry snow and ice into the windings. If an air washer is used, it will become clogged with ice. With the arrangement mentioned above, all or a part of the air can be taken from inside the motor room in winter weather. It is best to proportion the amount of air taken from each source so that the temperature in the duct is never below 50 degrees F. A single door or shutter arrangement should be provided for the two openings, arranged so that in closing one, the other is automatically opened. This will prevent the possibility of both openings being closed at the same time and depriving the motor of its ventilation. This door will serve as a damper for properly proportioning the amount of air taken from each source, the door being fixed in the proper intermediate position.

In the case of forced ventilated machines, the blower should be so interlocked with the control that it is impossible to operate the machines unless the blower is functioning. This can best be done by placing in the duct a vane which carries a contact in the control circuit, rendering the control inoperative unless the vane is deflected by air passing through the duct.

When ventilating air is forced into a motor room, the room must be designed with sufficient openings to provide free outlet for the air, so that a pressure will not be set up in the room and the influx of air opposed, thus diminishing the amount of air to the machines. The best plan is to install, near the roof, exhaust fans having sufficient capacity to expel the same amount of air as is forced in by the blower.

Sometimes it is not convenient to install a motor house, in which case the motor can be enclosed, as shown in Fig. 2, and artificial ventilation provided as described above. The most common instance of this is a hot sheet mill. Motors for this application are invariably located in a pit, where it is difficult to obtain the necessary change of air and the atmosphere is unusually warm and dirty.

Sweating is the result of a difference of temperature between the machines and the surrounding air. If the air is saturated at a certain temperature and is cooled below this point, it gives up some of its moisture. When the temperature of the machine is low enough to reduce the temperature of the air below the dew point, the excess moisture is precipitated upon the machines. This is very injurious to insulation and has a bad effect on the apparatus generally as it causes rusting of journals and other bright metallic parts and corrosion of the copper and brass. If the room temperature is kept uniform at all times, or if the machines are kept slightly warmer than the surrounding air, sweating will be prevented.

HANDLING

Extreme care should be used while unloading or otherwise handling large electrical apparatus as, from the nature of such apparatus, it is easily damaged by being allowed to slip or bump against anything. If the insulation is once broken, it is practically impossible to repair it, so that it is as good as it was originally, and the delay and expense occasioned by even a slight damage is out of all proportion to the extra effort required to "play safe" when handling this class of apparatus. Rope or cable slings should be used when lifting rotors

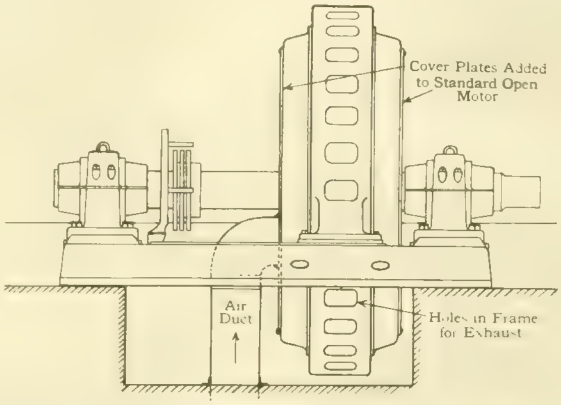

FIG. 2—STANDARD OPEN MOTOR ARRANGED FOR FORCED VENTILATION

By enclosing the ends. The air is brought in through one of the cover plates and allowed to escape through holes in the frame.

with cranes, and these should be so placed and separated with spacers that no pressure is exerted on the windings.

When possible a rotor should be supported from its shaft or spider. If it is necessary to place it on the floor, it should be set on a board not wider than the active iron. It should be borne in mind that a scar or dent in the laminations short-circuits them and partly nullifies the effect of the laminated construction. Eddy currents will be set up in the laminations so short-circuited which will cause a hot spot, and endanger the insulation at this point.

STORING

When electrical apparatus is received, it should be placed in a dry, clean store room and covered up to keep out dust and dirt. This storeroom should have an even temperature to prevent sweating.

ERECTING

The machines should be erected on substantial foundations, designed with reference to the subsoil at

the particular location so that they will not be thrown out of line by settling of the foundations. Motors should be securely anchored to the foundations and grouted in to guard against any unnecessary vibrations.

When setting machines on the foundations, particular care should be taken to line up all bearings correctly and see that they are clean. Journals should be examined for rough or rusty places and gone over carefully to see that they are in perfect condition before being placed in the bearings. The air-gap should be checked after the machine is set, and all bolts gone over to see that they are tight. Machines should be religned regardless of shop alignment, due to stresses which may be received during handling or shipment.

STARTING

After the machines are completely set up they should be thoroughly dried out before being started. This can be done by applying heat externally or by circulating current in the windings. Drying out externally can be done by placing resistance grids under the machines to dissipate roughly about one kilowatt per 100 horse-power rating of the machines. Care should be taken that no part of the hot grids comes in contact with the windings. The machine should be covered with a tarpaulin and an opening provided at the top to allow the escape of the moisture, otherwise it will condense on the machine again as soon as the heat is discontinued. A thermometer should be kept on the machines, and the temperature not allowed to exceed 90 degrees C. unless it is known positively that the insulation is of such a character that higher temperatures will not be injurious.

The time required to dry out a machine thoroughly will vary from a few days to several weeks, depending on the size of the machine and the condition of the insulation when starting. Insulation resistance should be taken two or three times a day at uniform intervals, during the period of dry out, and a curve plotted using resistance as ordinates and hours as abscissæ. A high-voltage megger is the most convenient method of measuring insulation resistance, but a high resistance voltmeter and an ungrounded 600 volt direct-current circuit can be used. In using a megger, the instructions coming with the instrument should be carefully followed or misleading and erratic results may be obtained. These readings should be taken when the insulation is warm. When using a high resistance voltmeter and an ungrounded 600 volt circuit, one side of the circuit is connected to the frame of the machine and the other side to the bare windings, through the voltmeter. The insulation resistance then equals,— $R = \frac{(V-v) \times r}{v}$ where, R = the insulation resistance; r = the resistance of the voltmeter; V = the line volts and v = the voltmeter reading. The temperature of the windings should be recorded at the time of taking the insulation resistance. This process should be continued until the curve shows that the insulation is thoroughly dry, i. e. until there is no further change in resistance.

Machines which have been dried out by applying external heat only, may show a very good value of insulation resistance with a megger and still have moisture in the insulation next to the conductor. This is particularly true of high voltage machines where the insulation is heavy and it is very difficult to entirely drive out the moisture. Hence a much more effective method is to apply the heat internally by circulating current. Machines of 2200 volts or higher can generally be dried by applying 220 volts alternating current, simply by connecting this circuit to the terminals without interposing resistance. This point should, however, be checked with the manufacturer or the machines can be watched very closely at first by observing thermometers placed on the coils to make sure that they do not overheat. The application of current directly to the coils presupposes that the insulation is in good enough condition to withstand this low voltage. If the insulation is in poor shape, external heat should be used until it is safe to apply a low voltage for circulating current. The same process of taking megger readings should be followed as is described above for external heating until the insulation on the resistance reaches a fixed value. The A. I. E. E. recommendation for insulation resistance is,—

$$Megohms = \frac{Voltage}{K. v. a. + 1000}$$

This value seems to be low and for some mill apparatus particularly 2200 volt machines, the machines should show at least one megohm per thousand volts. These values are not given with the understanding that the drying process should be stopped when these values are reached but, in every case, the process should be continued until a constant value is obtained. If this constant value does not equal that given above, the manufacturer of the apparatus should be notified.

Many machines are placed in service after the above precautions have been taken, but on large apparatus where continuity of service is important, many operators give the apparatus the same insulation test as it receives in the factory before shipment. Megger tests, although serving as a measure of precaution, cannot be entirely relied upon, as it is possible to show good resistance values when the insulation is on the verge of a breakdown. The only adequate method of measuring the ability of the insulation to withstand operating voltage is to apply actual potential test on the insulation. This requires a small transformer testing box designed to give a wide range of voltage. The test voltage can be applied for a period of one minute and if a weak point is found, very little damage is done, due to the small capacity of the transformer. On the other hand if the apparatus is placed in service without discovering this weak point, the apparatus itself may be connected to a power circuit having considerable capacity and when the breakdown occurs, the large amount of power available could damage the machine seriously. Such a breakdown occurs when the mill is in operation and its delay is serious. If a testing transformer is

used, this can be done before the equipment is started up and the repair made before the mill is placed in operation. Before this voltage test is made, the machine should be blown out and all brass and copper parts wiped clean as the presence of dirt may cause a failure, even when the machine is in good condition.

Before starting a motor, it should be thoroughly inspected to see that all bolts are tight, brushes operating freely in their holders, that there is nothing in the air-gap, that the bearings are oiled and, if water cooling is necessary, that the water is turned on. It is well to rotate the machine by means of a bar or crane before actually starting with current to make sure that it turns freely. After the machine is started and before it is brought up to full speed, it should be inspected to see that the oil rings are turning and actually bringing up oil and that no part of the rotor is striking. The bearings should be inspected every few minutes while bringing the machine up to speed and for four or five hours after it is up to speed, to insure that they are not generating excess heat. A thermometer should be placed on any bearing that shows a tendency to generate excess heat. This thermometer should be read at least once every five minutes and any sudden rise in temperature is the signal to shut down and examine the bearing, as it is probably "cutting", and will need to be scraped, and the alignment verified.

OPERATION AND CARE

After the machines are placed in regular service, the entire equipment should be kept clean, particularly the insulation. It is advisable to keep all machines painted as the paint will not only be a benefit to the machines by preventing rust and also making them easier to clean, but it will be an incentive to the operators and attendants to keep the motor-room and apparatus neat. This in itself helps to reduce maintenance. In addition to painting the iron and steel parts of the machines, the exposed parts of the windings, and particularly the creepage surfaces over the insulation, should be gone over at least once a year with a good insulating varnish. Most of these varnishes will air dry in from 24 to 48 hours with a room temperature of approximately 80 degrees F. If a shorter time is necessary, the varnish can be dried more quickly by covering the machines with a tarpaulin, leaving an opening at the top and placing resistance grids under the machine to dissipate energy as previously mentioned in this article. This treatment will cause the insulation to become smooth and glossy so that dirt will not adhere readily.

When operating the machines, the bearing water should always be kept running on such bearings as are designed for water cooling and, upon starting a machine, all bearings should be examined to see that the oil rings are turning and feeding the bearings with an ample supply of oil. The bearing oil should be kept clean and changed or filtered once a year or upon any evidence of dirt or grit. The question of the best grade of oil to use should be given careful study, particularly where oil ring lubrication is depended upon. It is sometimes found that the grade of oil giving the best results in some localities or seasons, will be too thick or too thin for the best results in other places or times. A little study and experimenting will enable a supervisor to determine the best grade of oil for his particular conditions.

Periodic inspections should be given to the entire equipment, say every week or two, at which time the machine should be thoroughly blown out with a moderate pressure air blast—about 25 or 30 pounds per sq. in. is the most satisfactory. As the mill line is usually high pressure, it is advisable to provide a reducing valve and water trap so as to obviate any danger to the insulation due to moisture or a high-pressure blast. In some cases a low pressure air compressor is installed for this purpose. Care should be taken to prevent dirt from getting into the bearings during this cleaning.

At these inspection periods, the insulation resistance should be measured while the machines are still warm, and a permanent record kept. This will show whether any deterioration of insulation is taking place, and preventive steps can be taken before an actual break-down occurs. During this inspection, all bolts and connections should be examined to see that they are tight, as they are liable to become loosened by the continual vibration and shocks from the mill. All switching and auxiliary apparatus should be regularly inspected also, as only by this means can satisfactory and continuous service be realized.

If at any time the machines are to be out of service for a while, they should be thoroughly cleaned and inspected mechanically and electrically, so as to be ready for operation on short notice. Tarpaulins should be used to cover the machines and if the temperature of the motor room is not uniform at all times, external heat should be used to keep the machines at a temperature that will prevent sweating. Where high voltage alternating-current machines are installed in localities having high humidity, schemes have been worked out whereby 220 volts alternating-current can be applied to the motor windings by simply switching the motor from its power line to the shop circuit. This can be done very quickly and only a small amount of power is required, as the heat is applied internally and it is only necessary to keep the temperature a few degrees above that of the surrounding atmosphere to prevent precipitation. It is customary to instruct the operators to apply this low voltage when the mill is shut down over the week-end or for any other period of appreciable duration.

In conclusion it should be emphasized that electrical equipment shows no external signs of fatigue or failure, and hence breakdowns, with resulting interruption to service, are much less liable to occur when the apparatus is systematically and regularly inspected.

Selection and Application of Electric Arc Welding Apparatus

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THAT the process of autogenous welding by means of the electric arc is not new, is evidenced by the fact that N. V. Bernardos of Petrograd secured a patent in 1887 for the now generally known "Carbon Electrode Process." A few years later, Slavianoff introduced a process for casting metal into blow holes of defective castings by producing an arc between an electrode consisting of a metallic rod, and the casting to be repaired. This was the beginning of the metallic electrode process which has come into such wide use within recent years. That even greater advantage has not been taken of the arc welding process is due chiefly to the haphazard methods of applying the process and lack of proper supervision and inspection methods.* This condition is due primarily to the lack of sufficient scientific knowledge which can only be secured by extensive and persistent research investigations to determine the proper methods, materials and apparatus which must be used to secure the best results.

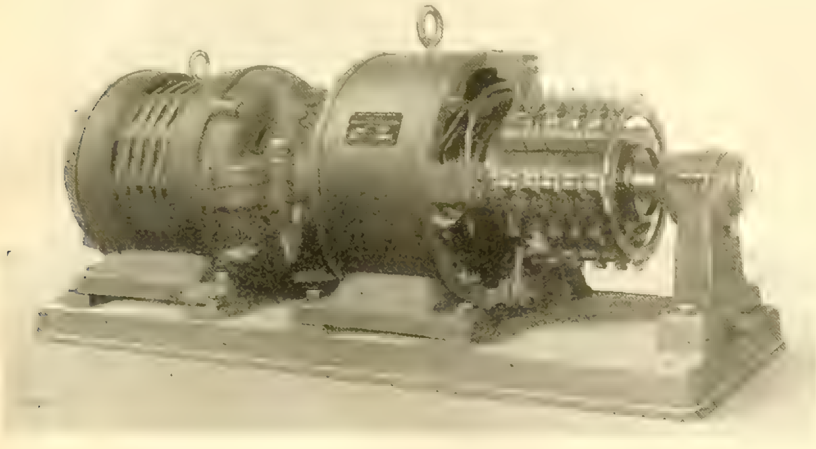

FIG. 1—60 VOLT, 500 AMPERE, MOTOR GENERATOR SET

During the last two or three years, a number of manufacturing companies have been conducting scientific investigations and much valuable data has been published which will result in more extensive applications of electric arc welding. In a great deal of such literature, however, much stress has been laid upon the supposedly essential merits of certain welding systems—automatic systems of heat control of the arc—and discussion of constant current systems versus constant potential systems. These discussions and the tendency of most welders to consider themselves pioneers in a generally unknown art, "enshrouding themselves in a hallowed glow of mysterious camouflage," have resulted in no little confusion of unsophisticated persons who have attempted to get at the facts.

The three chief requisites for electric arc welding are: *1*—a suitable form of electrical energy and control; *2*—electrode material of proper characteristics, and *3*—an experienced and trained welder or operative. It is hardly correct to say that any one of these factors is the most important. However, securing proper electrical equipment and electrode material, when once accomplished, dismisses the first two factors, whereas securing suitable men to be trained often resolves into an appreciable problem and therefore many authorities have placed the importance of the third factor at 90 percent of the total problem. It is not within the province of this article, however, to attempt discussing any but the electrical equipment and application thereof.

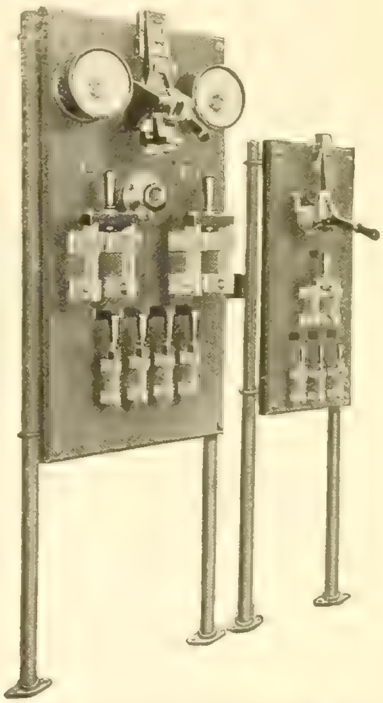

FIG. 2—COMBINATION GENERATOR CONTROL AND WELDING PANEL (LEFT), AND WELDING CIRCUIT OUTLET PANEL (RIGHT)

ALTERNATING-CURRENT ARC WELDING

Under proper conditions, alternating current may be used for arc welding but at present direct current is found to be much more satisfactory. The difficulty of maintaining an alternating-current arc is so great, when a resistor only is used in series with the arc obtaining power from a 110 volt, 60 cycle circuit, that this scheme may be considered at present as commercially impracticable, especially if a bare electrode is used. If

*See article entitled "Inspection of Metallic Electrode Arc Welds", by O. H. Eschholz, in the *Railway Electrical Engineer*, for July 1918, p. 199.

a covered or slag coated electrode is used, the difficulty is somewhat decreased. If, however, a suitable reactance is placed in series with the arc, then the operation is practically on a par with the direct-current process. To produce this condition, it is necessary to have the reactance designed so that the power-factor of the welding circuit is at least as low as 25 percent. If the potential of the available supply circuit is 220 volts, or higher, a transformer must be used. In this instance, it is not necessary to use a separate reactance, as the transformer can be designed for the service. If the design, however, is such that the resulting power-factor is 50 to 60 percent, then the difficulty experienced will be almost as great as attempting to weld with a resistance only in the circuit when using a bare electrode. It is reasonably safe to predict, therefore, that until some commercially satisfactory static apparatus for power-factor correction is developed, or until a comparatively new and entirely satisfactory electrode of the coated, cored or alloy type is developed, the application of alternating-current arc welding will probably be confined to a very limited field.

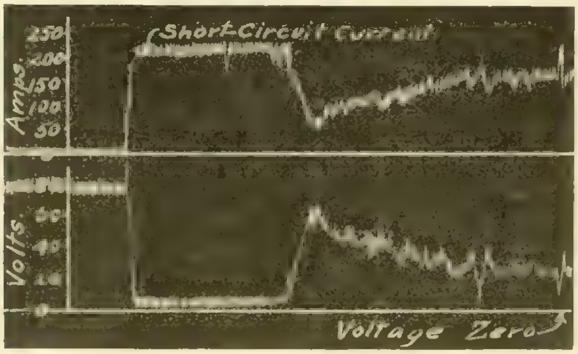

FIG. 3—CHARACTERISTICS OF ARC WELDING CIRCUIT
With metal electrode having resistance only in series with the arc. Power supplied by 500-ampere constant-potential generator.

DIRECT-CURRENT ARC WELDING

When using direct current, the potential across the arc will be between 40 and 60 volts if a carbon electrode is used; whereas, the arc potential should be about 22 to 18 volts (preferably the latter) when a metallic electrode is used. It is obvious, therefore, if the available source of power is a commercial direct-current circuit of 220 volts or higher, that some form of apparatus is required so that the arc will be operated at the proper voltage and with satisfactory stability. For such service, a simple resistance with suitable controlling device may be used, but this is objectionable for several reasons. First, an unnecessarily large amount of power is wasted in the resistance. Second, the high voltage available will permit a careless operator to draw an extremely long arc with the metallic electrode, resulting in poor welds. Third, the resistance required for each welding circuit is unnecessarily large, requiring increased floor space, and is heavy and expensive. For these reasons, therefore, from commercial and engineering standpoints, it is better practice to install rotating electrical equipment for transforming from the high potential to that required for arc welding service. For this service, the rotating equipment is a motor-generator set, as illustrated by Fig. 1. In some instances, rotary converters have been used, but the use of these will probably be quite limited, as there are a number of objections. First, in practically every instance, a special set of transformers is required. Second, the direct-current voltage is usually almost a direct function of the alternating-current voltage. Third, a converter is not as simple to start as the ordinary induction motor-generator set. Fourth, the cost of a rotary converter and transformers will usually be practically equal to or greater than a comparable induction motor-generator set. Fifth, the overall efficiency of the converter and transformers will be little better than the motor-generator. Sixth, the total floor space required by the rotary converter and transformers will be equal to or greater than that required by the motor generator.

Two welding control panels are illustrated in Fig. 2 the one at the left being a combination for the control of a generator, one welding circuit and an additional feeder switch for supplying power to a welding circuit

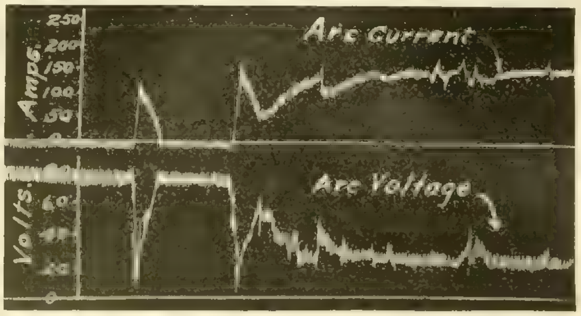

FIG. 4—CHARACTERISTICS OF ARC WELDING CIRCUIT
With resistance and reactance in series with the arc.

panel removed from the combination panel. Such a welding circuit (outlet) panel is illustrated by the right hand panel in the cut. The single-pole switches are connected to the stabilizing resistance so that various current values can be obtained for welding by throwing the switches in the proper combinations.

ELECTRIC ARC PHENOMENA

Any electric arc is inherently unstable. To clarify this statement, assume that a current of certain value is caused to flow between two electrodes separated in atmosphere a fixed distance. Under these conditions, a certain difference of potential will exist between the electrodes, which is usually spoken of as the arc voltage. Now, as the current through the arc is increased, the resistance of the arc and the voltage drop across the arc will actually decrease. The voltage does not decrease as rapidly as the current increases and, therefore, increased current is accompanied by increased wattage in the arc. It is obvious, therefore, that if an arc is to be operated by power from a constant potential circuit, it is necessary to have a resistance in series to limit the flow of current; this is known as stabilizing the arc. On the other hand, if the arc is

to be supplied with power directly from a generator, then the generator must be designed to have a drooping voltage characteristic suitable for the service.

It has been determined that an arc drawn between a carbon and metal electrode will be satisfactorily stable, when the voltage drop across the stabilizing (ballast) resistance in series with the arc is 50 percent or more of the arc voltage. An arc drawn between two metal electrodes is somewhat less stable; furthermore, when using the metallic electrode for welding, conditions prevent the operator from maintaining a fixed arc length; therefore, if the resistance drop is about twice the arc voltage, the results obtained are much more satisfactory. Fortunately, carbon electrode welding is entirely satisfactory when the arc is operated at 35 to 50 volts and metallic electrode welding is most satisfactory when the arc is operated at 22 to 18 volts, preferably the latter. Therefore, a constant potential generator developing 75 to 60 volts, represents the most balanced design relative to economical and satisfactory service. In fact, 60 volts has proven entirely satisfactory and reduces the cost of the electrical equipment and also the cost of power. Generators of the constant potential type developing voltages as low as 35 have been tried out in service but have not proven as satisfactory as higher voltage machines. This is due to the increased difficulty of maintaining a fixed arc length, especially when using a metallic electrode. As a result, the operative is troubled by continually losing his arc, which reduces production.

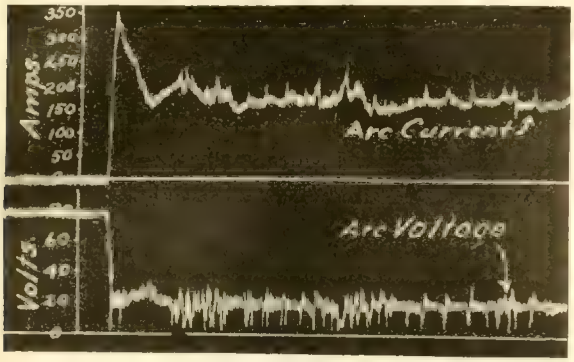

FIG. 5—CHARACTERISTICS OF ARC WELDING CIRCUIT

With reactance only in series with the arc. Power supplied by means of a 150 ampere constant current generator.

CONSTANT CURRENT VS. CONSTANT POTENTIAL GENERATORS

For arc welding service, it is eminently desirable to have the proper current for the welding circuit maintained at a reasonably constant value, because the rate of fusion is a function of the current and is practically independent of the arc voltage. Insofar as results at the arc are concerned, it is absolutely immaterial whether the source of power is a constant potential or a constant current generator. In the case of the constant potential equipment, the arc current is maintained reasonably constant by the resistance in series with the arc, as illustrated by Fig. 3. If, in addition to the ballast resistance, a small reactance is connected in series with the arc, the current will be maintained even more constant, as illustrated by Fig. 4. The chief advantage of the reactance, however, lies in its ability to limit the short-circuited arc current when striking the arc. Fig. 3 indicates an average welding current of approximately 160 amperes, whereas the short-circuited arc current is about 215 amperes or about 35 percent higher. Fig. 4 indicates that the reactance actually kept the short-circuit current from exceeding the average welding current. The reactance which was used for the test is undoubtedly larger than is necessary for commercial welding circuits. The chief advantage gained by reducing the short-circuit current is that the tendency for the electrode to stick (freeze) to the work is materially reduced, thereby enabling the operator to strike the arc with a cold metallic electrode much more easily. For this reason, the use of a small reactance is recommended for each welding circuit, especially for inexperienced operatives or when new men are to be trained for arc welding service, even when power is obtained from a constant potential system.

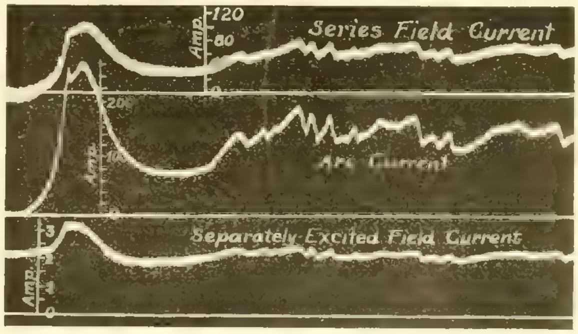

FIG. 6—CHARACTERISTICS OF ARC WELDING CIRCUIT

With a reactance about 20 times that of Fig. 5 in series with the arc and using a different make of constant-current generator.

Constant-current generators have been developed in two classes; one where an individual generator or motor-generator set and control equipment is supplied for each welder; the other where the generator or motor-generator supplies current for two or more welding circuits all of which are in series. The constant current generators of the individual type as developed at the present time require the use of a comparatively large reactance in series with the arc before the resulting current characteristic is even as good as that of the constant potential circuit. This is illustrated by comparing Figs. 5 and 6, which show arc current characteristics of two different constant current generators, with Fig. 3. The first generator had a reactance of 0.55 ohms in series with the arc. The current varies somewhat during operation, having an average value of about 175 amperes. The initial current when the arc was struck, reached a maximum value of about 325 amperes, or an increase of about 85 percent above the average. This reactance is the same as that used in the constant potential circuit, the characteristics of which are illustrated by Fig. 4. The inherent characteristics

of the second generator are so much poorer than the first that it was necessary to use a reactance approximately twenty times greater to produce the arc current curve illustrated by Fig. 6. In this case the average welding current is about 160 amperes and is subject to large and violent fluctuations. The current at the instant of striking the arc reached a maximum value of about 260 amperes or an increase of 75 percent above the average.

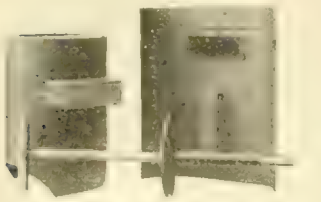

FIG. 7—CARBON ELECTRODE HOLDER IN FOREGROUND, HOOD AT LEFT, AND SHIELD AT RIGHT

The series arc type of constant-current generators requires the use of a somewhat complicated form of control for each operator's circuit. This is necessary because the various welding circuits are connected in series, the function of the control being to prevent interference of the various arcs when the operators start and stop welding. In order to maintain the proper arc polarity, it is essential that the work on which each operator is welding, be electrically insulated from the work of all other welders, operating from the same circuit. For this reason, therefore, the field of application is somewhat limited.

PROTECTIVE EQUIPMENT AND ACCESSORIES

The electric arc is very prolific in the radiation of ultra-violet light, which will produce a severe case of sunburn if any uncovered portion of the human body is within a few feet of the arc for a period of ten to fifteen minutes. For this reason, it is necessary for the operator to wear heavy closely woven clothing, completely covering the body, arms, and limbs. For the protection of the hands and wrists, leather gaunlet gloves or a double pair of cotton gloves are used. For the protection of the head, neck and face, a hood is desirable, as illustrated at the left in Fig. 7. The hood should preferably be made of non-conducting material, because it is necessary many times for the operator to weld in very close quarters. Under this condition, if the hood is of metal, such as aluminum, the operator may be burned by molten metal if by accident his electrode or electrode holder strikes the hood when some portion of the hood is in contact with some part of the work being welded. The hood illustrated is designed to rest on the shoulders and against the back of the operator's head. A different protective device is a mask, Fig. 8 which is similar to the front vertical half of a hood, and is held in place on the operator's head by a suitable head gear. Still another form is that of a shield illustrated at the right of Fig. 7 which is provided with a handle and is held in the free hand of the operator. Each of these devices must be provided with some transparent material such as mica or glass so the operator may observe his work. The glass must perform the following functions:

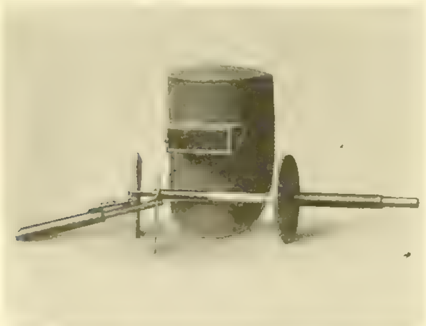

FIG. 8—WELDER'S EQUIPMENT

Mask in center, metallic electrode holder at left, and carbon electrode holder at right.

1—Filter out practically all ultra-violet and most of the infra-red radiations from the arc.

2—Reduce the intensity of the visible spectrum or light to a value which will not result in glare.

3—Transmit to the eye a light predominated by the amber shade which will reduce eye fatigue.

4—The surface of the glass must be sufficiently true and have satisfactory optical qualities to produce good definition, so the operator can readily see the work without experiencing eye strain.

Probably the best all around protective device for the head is the hood, as it protects the face, back of head, and front and back of the neck. The protection of the back of the neck is important when the operator is working in restricted quarters, especially if the surrounding surfaces are of a medium or good reflecting type. For example, some booths provided for welding small articles, such as tools, make it imperative for the operator to use the hood.

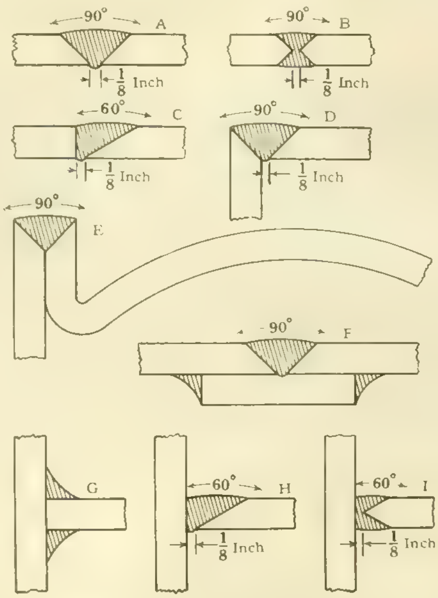

FIG. 9—TYPICAL SCARFS FOR PLATES GREATER THAN ONE-EIGHTH INCH IN THICKNESS

A—Double beveled butt weld; *B*—Double Vee butt weld; *C*—Single beveled butt weld; *D*—Double beveled corner weld; *E*—Double beveled pressure tank weld; *F*—Double beveled butt-strap weld; *G*—Double fillet Tee weld; *H*—Single beveled Tee weld; and *I*—Single Vee Tee weld.

In view of the above statement, it is obvious that a suitable enclosure should be provided for each welding station, if the work is to be performed in the vicinity of other workmen, as is the case in a machine shop.

To enable the operator to use the electrode material, it is necessary to provide him with electrode holders, two types of which are shown in Figs. 7 and 8. The carbon or graphite electrode holder is provided with a simple effective clamp which grips the electrode. The handle is provided with a disk to protect the hand

against the heat from the arc, and must be designed so that the heat of the cable will not make the hand grip too hot. The metallic electrode holder is somewhat smaller than the carbon holder because smaller currents are employed. The electrode clamping device must be simple and rugged, must hold the electrode securely and also permit replacement readily as in operation a new electrode is required about every one and one-half to two minutes. The electrode gripping surfaces must be protected against pitting by flying metallic particles and the design of these parts must permit the wasting

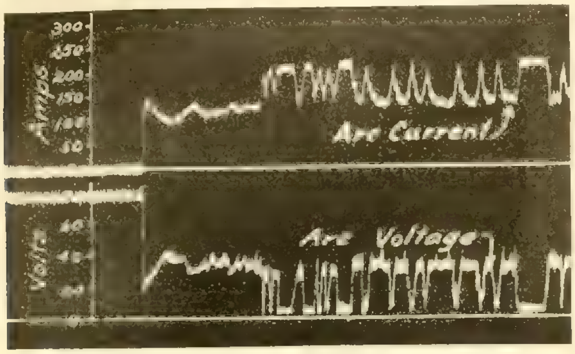

FIG. 10—CHARACTERISTICS OF ARC WELDING CIRCUIT
Using a hot-rolled steel electrode.

of a minimum amount of the electrode. Like the carbon holder, the metallic electrode holder handle must be designed so that it does not become uncomfortably heated by the conducting cable attached to the holder. The heat in the conducting cables is produced not only by the current flowing, but also by heat conducted back from the hot electrode. This is particularly true of the carbon holder, as the carbon will become heated to a

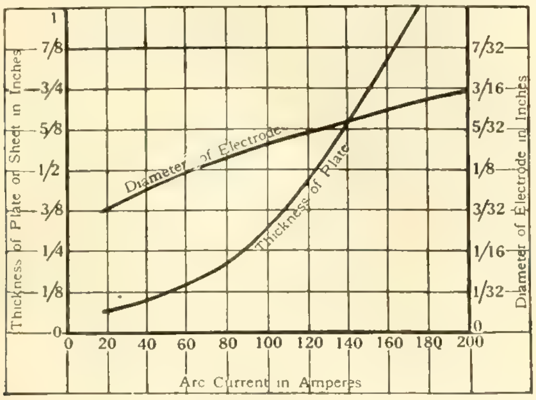

FIG. 11—RELATION OF APPROXIMATE ARC CURRENTS AND ELECTRODE DIAMETERS

For welding steel plate of various thicknesses. To find the diameter of the metallic electrode required, select, for example, a three-eighths inch plate and follow horizontally to the *Thickness of Plate* curve. The vertical line through this intersection represents about 110 amperes as the most suitable current to be used with this size of plate. Then follow this vertical line to its intersection with the *Diameter of Electrode* curve which locates a horizontal line representing approximately five thirty-seconds inch diameter electrode. In a similar manner a one-half inch plate requires about 125 amperes and a five thirty-second inch electrode.

white incandescent value in welding and especially in cutting service. Both of the holders must be designed so that with the conducting cable attached, the balance in the hand of the operator will be satisfactory, so as to reduce wrist strain to a minimum.

WELDING PRINCIPLES

To produce satisfactory electric arc welds regardless of the metal welded, there are six fundamental principles which must be observed carefully:—

1—Proper preparation of material to be welded.

2—Selection of electrode material of proper physical, chemical and electrical characteristics.

3—Use of proper current value.

4—Maintenance of proper arc length.

5—Proper sequence of preliminary tacking and final filling or welding.

6—Proper heat treatment subsequent to welding.

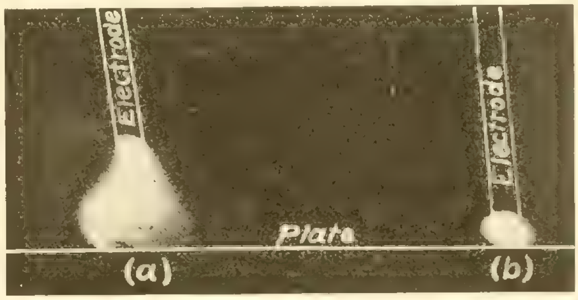

FIG. 12—WELDING ARCS

(a) Long arc of 175 amperes showing deflection of arc stream to left and oxide flame being blown to right, thereby exposing the new metal. (b) Short arc of 175 amperes showing concentration of gases completely enveloping the newly deposited metal. By reason of the intensely actinic light from the arcs, the electrodes and the plate did not show in the photograph, and their position was sketched in on the print.

PREPARATION OF WORK FOR WELDING

It is always necessary to prepare the surfaces of the material to be welded, so that they are readily accessible to the new material to be deposited. If the

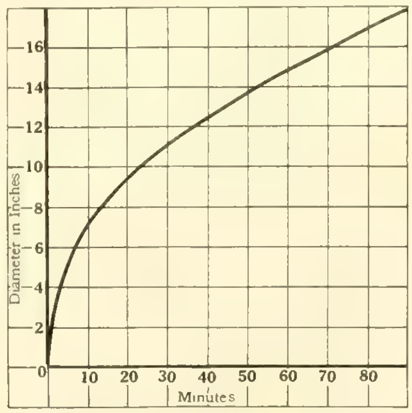

FIG. 13—RATE OF CUTTING CAST IRON OF CIRCULAR CROSS-SECTION
With a one inch diameter carbon electrode at 625-650 average amperes and 45-65 arc volts.

edges of two plates are to be welded together with the plates in a common plane, then the edges should be beveled to an angle of 45 degrees, making a total of 90 degrees in which to deposit the new metal as illustrated by *A*, Fig. 9.* If the pieces can be turned for welding from both sides, then both edges of each plate may be beveled and only one half as much new metal will be required to fill the angles. The apex of the

*The importance of the angle is shown by Figs. 4 and 5 of an article by O. H. Eschholz in the JOURNAL for July 1918, p. 248.

beveled edges should not be closer than one eighth inch to insure a good weld. When cracks in castings, etc., are to be repaired, the material should be beveled along the cracks in a similar manner. In every instance, all heavy oxide scale, rust, dirt, grease, sand or any other foreign material should be thoroughly removed from

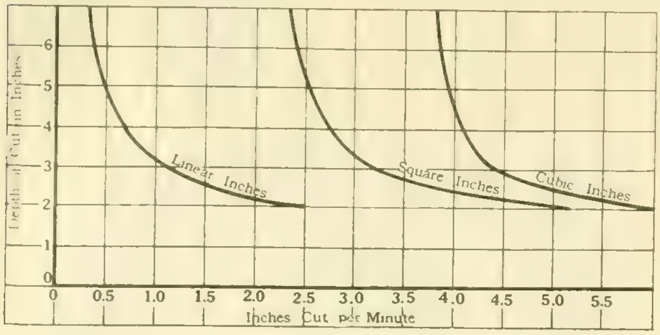

FIG. 14—RATE OF CUTTING CAST IRON PLATES

With a one inch diameter carbon electrode at 625-650 average amperes, 45-65 arc volts. The length is greater than the depth of the cut which is made progressively in one direction.

the immediate vicinity of the surfaces to be welded. In some cases, after completing the mechanical preparation, it is advisable to preheat the material to assist the welding operation.

SELECTION OF ELECTRODES

The use of metallic electrodes for arc welding has proven more satisfactory than the use of carbon or graphite electrodes which necessitates feeding the new metal into the arc by means of a rod or wire which is melted. The chief reason for this is that when the metallic electrode process is used, the end of the electrode is melted, the molten metal being carried through the arc and deposited at the other end of the arc on the material being welded at which point the material is in a molten state produced by the heat of the arc,

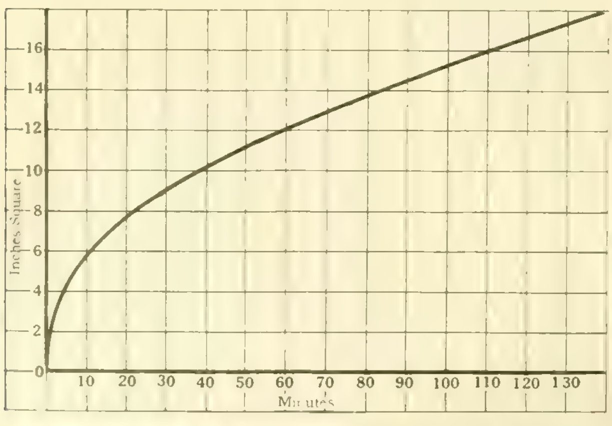

FIG. 15—RATE OF CUTTING CAST IRON SQUARE BLOCKS

With a one inch diameter carbon electrode at 625-650 average amperes; 45-65 arc volts.

thereby producing a perfect union or fusion with the new deposited metal. In the hands of an experienced and careful welder, good results can be obtained with the carbon electrode process. However, if the operator is inexperienced or careless, he is liable to fail to produce good fusion continuously due to feeding in the new metal too rapidly. As a result, the new metal will flow over portions of the work which have not been brought to the molten or fusing state. Probably the chief field of usefulness for the carbon electrode is that of cutting or for rapid repair welding where strength of weld is not as important as the speed of doing the work.

For metallic electrode welding of mild steel plates, an electrode containing about 0.17 percent carbon and 0.5 percent manganese, has been found most satisfactory. The percentage of phosphorous, sulphur and silicon should be as small as possible, not exceeding 0.03 to 0.035 percent for the first two, and not over 0.01 to 0.015 percent for the last. This same material is also satisfactory for welding steel castings, and cast iron castings, including the malleable variety. When subsequent machining is to be done on cast iron cast-

FIG. 16—SEQUENCE OF WELDING A PIECE OF HIGH-SPEED STEEL TO A CARBON TOOL STEEL SHANK

a—Steel shank forged to shape and piece of scrap high-speed steel cut to shape; *b*—High-speed steel tacked to shank; *c*—Weld completed; *d*—Finished tool ground and tempered.

ings, better results can be obtained by using a copper-aluminum alloy electrode and a suitable flux. Some operatives have found that excellent results can be obtained by depositing a comparatively thin layer of the alloy over all the prepared surfaces, after which the main body of the weld is made with the steel electrode mentioned above.

That the proper chemical constitution of the electrode material does not necessarily determine its suitability for welding, is illustrated by Fig. 10. The only difference between these conditions and those for Fig. 4 is that a hot rolled steel electrode was used, having an analysis of about 0.15 percent carbon, 0.5 percent manganese, 0.012 percent phosphorous, 0.045 percent sulphur and 0.011 percent silicon. This electrode for some reason had a tendency to pass through the arc in large globules which partially short-circuited the arc, result-

ing in the current peaks illustrated, in spite of the reactance in the circuit. This illustrates the fact that the constancy of the arc current is not entirely dependent upon the characteristics of the electrical apparatus. A study to determine the most desirable characteristics for electrode materials is now being carried on by several leading manufacturers, therefore marked developments along this line may be expected in the future.

WHAT CURRENT SHALL BE USED?

The diameter of the metallic electrode required is determined by the current, which is dependent upon the thickness of the plate to be welded when the thickness is three fourth inch or less. Average values for

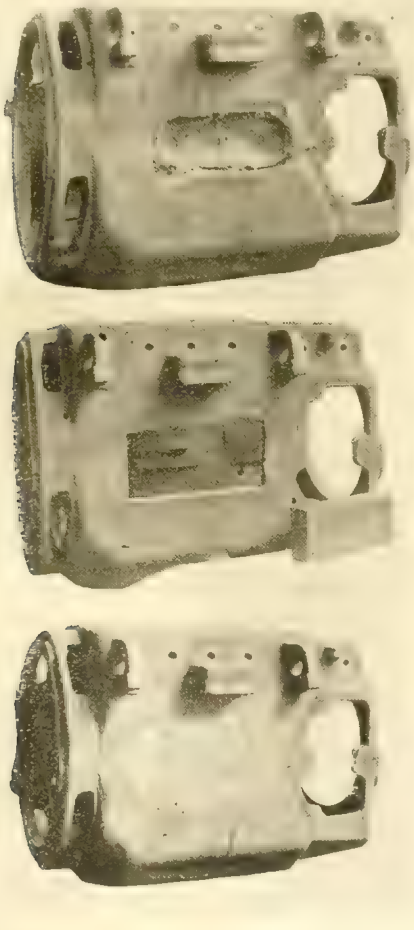

FIG 17—REPAIRING A RAILWAY MOTOR CASTING BY ARC WELDING

Showing how sand holes were found in the casting when being drilled (top) and how the metal was cut away with a carbon electrode before inserting the steel block shown at the lower right side (middle) and the repair completed (bottom).

welding of mild steel plates are indicated in Fig. 11. These values of current for plate thickness are only approximate, however, as the temperature of the plate will materially influence the volume of current which can be used. For example when making a lap weld between two overlapping one-half inch steel plates at ordinary air temperature of about 65 degrees F. it has been found that the best results were obtained by using a current of about 225 amperes and a three sixteenth inch diameter electrode. The explanation for the high current permissible is the tremendous heat storage and dissipation capacity of the lapped plates.*

SHORT ARC IS ESSENTIAL

The maintenance of the proper arc length for the metallic electrode process is very important. The arc should be just as short as it is possible for a good welder to maintain it. Under normally good conditions, the arc length should be such that the voltage drop never exceeds 25 volts and for best results, the potential should be between 18 to 22 volts. For a 175 ampere arc, the actual gap will be about one eighth inch. If the arc is maintained long as indicated by Fig. 12 (a), the natural air drafts will cause it to move around an extended surface of the work, preventing good fusion, and causing a thin deposit of new metal.* This also permits atmospheric oxygen to come in contact with the molten deposit, resulting in burning and porosity of the surface.** If, however, the arc is maintained short as indicated by 12 (b) much better fusion is obtained, the deposited metal will "bite into" the work, and the new metal will be confined to a smaller area.† Furthermore, the surface of the deposited metal will be better protected by the envelope of inert gases which surrounds the arc stream, thereby reducing the burning and porosity of the new metal's surface.‡

FIG. 18—SINK HEAD

To be cut from castings with the carbon electrode process.

Electrically-operated switching devices have been developed, which prevent the welder from drawing a long arc by automatically "killing" the arc when it has reached a certain length. These devices perform their function satisfactorily, but are subject to several criticisms. First, they entail a needless expense both of first cost and maintenance, because a man who will ultimately make a good welder can be made to see the desirability of maintaining a short arc and will, therefore, do so automatically within reasonable limits. Second, not even the most skilled welder can maintain a continuous arc never exceeding 25 volts. In fact, momentary variations of arc length due to involuntary reflexes of the operator's arm muscles, may occur quite frequently, but will not be of sufficient duration to re-

*The importance of proper current value in determining the strength of a weld, is indicated by Figs. 7 and 8, p. 248 in the JOURNAL for July, 1918.

*As indicated by Fig. 2, in the JOURNAL for July 1918, p. 247.

**As illustrated at right side of Fig. 3, in the JOURNAL for July 1918, p. 247.

†As indicated by Fig. 1, in the JOURNAL for July 1918, p. 247.

‡As indicated by the left hand side of Fig. 3, in the JOURNAL for July 1918, p. 247.

sult in appreciable damage to the weld. If, therefore, a switch is provided to kill the arc automatically when the voltage drop reaches 25 to 30 volts, the operator will be troubled by having to restrike his arc quite frequently, which will decrease his production.

FILLING SEQUENCE

When making a long seam weld between two plates, the operator is always confronted by the problems of expansion and contraction, causing warpage of the plates and the production of large internal strains, both in the plates and deposited material. To minimize these difficulties most satisfactorily, some operators have found by practical experience, that the best method to pursue is as follows:—After properly preparing the edges of the plate, light tack welds are made about eight inches apart along the entire seam. The operator then makes a complete weld between the first two tacks and then skips three spaces and welds between the fifth and sixth tacks and so on until end of seam is reached. This skipping process is again repeated by starting between second and third tacks and so on until the complete seam is welded. The object is to permit the heat in a restricted area to be dissipated and radiated before additional welding is performed near that area, therefore, the weld is made on reasonably cool sections of the plates, which keeps the expansion at a minimum. This is one example of numerous shop kinks, which are evolved by alert, aggressive welders, and is known as the "rigid method" of welding plates.

FIG. 19—STEEL SUPPORT FOR AXLE BRACKET WELDED IN PLACE

This support was omitted from the pattern and was welded in position and has withstood more than three years of service.

HEAT TREATMENT OF WELDS

The question of subsequent heat treatment of welded materials is a very broad one and represents a field offering opportunities for a vast amount of research and investigation by metallurgists. In general, however, ordinary commercial welding of mild steel plates and steel castings, if properly executed, will not require subsequent heat treatment. When cast iron castings are to be welded, it is often desirable to preheat the parts before welding and thoroughly anneal the work after welding, to relieve internal strains and minimize hard spots in the weld.

FIG. 20—BUILDING UP BY ARC WELDING, THE COUPLING END OF A STEEL MILL PINION

Worn parts are shown by the white lines.

GAS VS. ELECTRIC ARC

The oxyacetylene flame is not as intrinsicly hot and the heat is not nearly so concentrated as that of the electric arc. For this reason, the chief welding field for gas at present is that of thin sheet metal of less than one sixteenth inch in thickness. Since the gas flame is not as hot and concentrated as the electric arc, the time required to perform a weld is in the ratio of 2 or 3 to 1. This condition together with spreading of flame, results in much trouble due to expansion and contraction of mild steel plates. The actual difference in cost of gas and arc welding has been found by some investigators to be as high as 3:1 in favor of the arc,

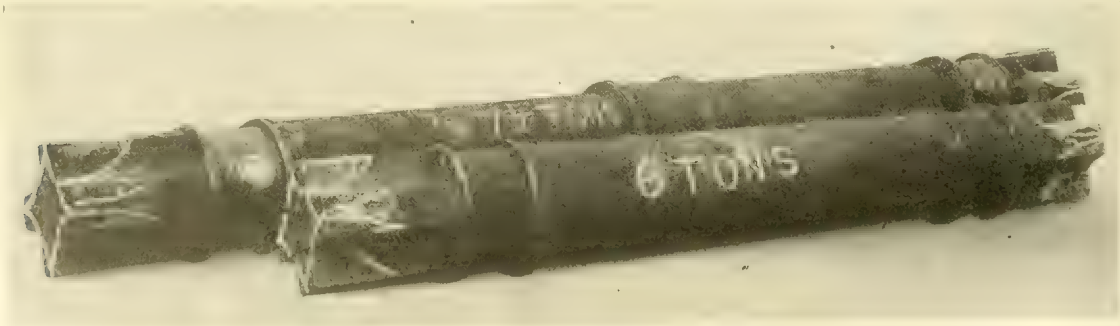

FIG. 21—STEEL MILL DRIVING SPINDLES

Built up at worn positions shown by white lines.

taking all charges into account. The gas process is also subject to the criticism of the carbon electrode process, namely, that it is possible for a careless or inexperienced welder to melt the filling material too rapidly, thereby causing it to flow over unfused surfaces of the work, which produces a weak weld.

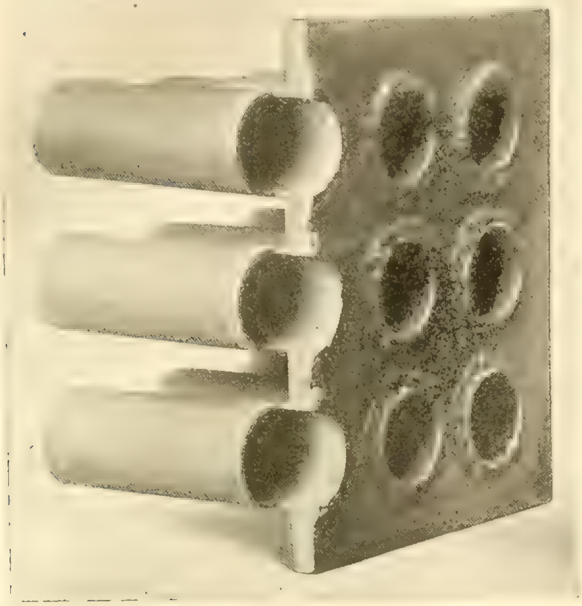

FIG. 22—BOILER FLUES WELDED TO FLUE SHEET

In the field of cutting, the gas flame is preeminently the better for cutting mild steel plates, angles and shapes. For this work, the acetylene is reduced to a minimum sufficient to support the flame, whereas the oxygen is supplied in great quantities. The action produced is that of oxidization or burning, which takes place very rapidly, with the removal of a minimum amount of material. Cast iron, however, contains such a large percentage of carbon, both combined with iron and in the free state, that the burning process cannot be

FIG. 23—STAY BOLT HEADS AND PATCH
Welded in locomotive fire box.

used. The metal must be actually melted and therefore the electric arc is faster than the gas, owing to the difference of the intrinsic heat values.

FIELD FOR ELECTRIC ARC WELDING

The field for the use of electric arc welding is very extensive; in fact, thousands of dollars worth of material is scrapped every year by machine shops, foundries and manufacturing establishments, a very large proportion of which can be reclaimed at a comparatively slight expense by electric arc welding.

Machine shops can use arc welding for reducing cost of tools for machining operations, by welding small sections of high-speed steel (obtained from scrap) to shanks of carbon tool steel, as illustrated by Fig. 16. Errors in machining can be rectified by depositing new metal and re-machining. Castings which reveal defects when being machined can be repaired as shown by Fig. 17.

FIG. 24 WELDING A WORN TRUCK SPIDER

Foundries can use the carbon electrode process for cutting risers and sink heads off of castings, as indicated by Fig. 18. Defective castings may be reclaimed as illustrated by Fig. 19.

Steel mills can reclaim rolls, driving pinions and driving spindles as shown by Figs. 20 and 21.

Railroad locomotive repair shops use electric arc welding extensively for various applications, shown by

FIG. 25—CORRODED SURFACE OF LOCOMOTIVE BOILER'S MUD RING
Built up by arc welding, as indicated in white.

Figs. 22, 23, 24 and 25. In fact, some locomotive manufacturers use arc welding for the entire fire box construction and in some instances, the entire boiler has been electric arc welded. In the railroad field, the savings resulting from arc welding vs. other methods is astounding*, in fact, one railroad has found that welds can be made by the arc process for about one third of the total cost incurred when the gas process is used.

*See paper on "War and Welding", by E. Wanamaker, in Vol. 30, No. 1, September issue of *"Proceedings of Western Railway Club."*

The ship building industry has recently been taking a very great interest in electric processes, both for construction of minor portions of steel vessels, and also with a view to building ships electrically welded almost throughout, thereby replacing to a great extent the present riveted construction. This latter accomplishment may be somewhat in the future, but there are so many fittings and parts which can be successfully welded at a reduced cost and a saving of time, that every shipyard building steel ships is vitally in need of electric arc welding apparatus.

The Protection of Electrical Apparatus

P. M. LINCOLN

ELECTRICAL apparatus differs from other machinery particularly in that the use of electrical insulation in one form or another is invariably required and the usefulness of the machinery is dependent in turn upon the integrity of this electric insulation. It is the object of this article to review briefly the various methods by which the integrity of electrical insulation may be secured and permanently assured.

Insulation of new electrical apparatus is designed to withstand the application of somewhat more than twice the normal voltage of the circuit upon which the apparatus is used.* But insulation is subject to deterioration and the operator of such apparatus should take means to assure himself, from time to time, that this insulation still remains in proper condition. About the only way this result may be secured is, to apply insulation tests to the apparatus periodically. Just what proportion of the original test it is necessary or advisable to apply is an open question. The double voltage applied when the apparatus is new is presumably a larger margin of safety than is reasonable after the apparatus has been in service for a period of years. It is the writer's opinion that 150 percent of normal voltage is the minimum to which the insulation should be allowed to deteriorate; if the insulation will break down on the application of 150 percent of normal voltage, the apparatus should be rewound or some other radical steps should be taken. The opinion of other engineers may place this value at some other proportion of normal voltage.** The crux of the matter is that it is necessary to maintain the insulation of electrical apparatus in good condition before the user of that apparatus can be assured that it is not on the verge of break down at any time, and the only way to obtain this assurance is by these periodical insulation tests.

Even when insulation is new and in good condition, it is always subject to break down, due to electrical conditions which may set up voltages in excess of the double voltage or more which it is designed to withstand when new. The most prolific source of excessive voltages is lightning, and lightning arresters of approved design should always be used for the protection of electrical circuits. Even when these are used they do not necessarily give perfect protection at all times and insulation break downs are apt to occur.

Electrical surges may, however, be set up by a number of conditions. Outside of lightning, the most prolific cause of surges is probably the arcing ground, The arcing ground is not a solid connection to ground; and when an electrical system is connected to ground through an arc, the point that is grounded does not necessarily assume ground potential at once. There is an oscillation in potential of the whole electric circuit, which is emphasized by the unstable character of the arcing connection to ground. If the electrical system is a small one, this surging may not be enough to do any particular damage. As the electrical system increases in size and capacity, the surging which takes place with an arcing connection to ground increases in intensity, and when the electrical system is of some considerable size, an arcing ground is almost sure to be disastrous, since the surging is very liable to become great enough to break down the insulation of the system at some point. The specific remedy for this condition of surging is to ground the neutral. The grounded neutral prevents the electrical system from oscillating its potential with respect to ground and consequently prevents another casual ground at some other point in the system from setting up electrical surges in the system. Grounding of the neutral is, therefore, a remedy that should be applied to all electrical systems, and the larger the system becomes, the more important becomes the application of this remedy.

The grounding of the neutral, although it prevents surges from being set up by casual arcing grounds, introduces other difficulties. If the neutral of a system is not grounded a casual ground at some other point of the system does not create a short-circuit, whereas, if the neutral is grounded, a casual ground at some other point does make a short-circuit. With a neutral grounded, therefore, there will occur short-circuits on the system which would not occur otherwise, and means should be taken to minimize the effect of these short-circuits. A certain amount of resistance in the connection between the neutral and the ground is usually rec-

*When electrical apparatus is new it is subjected to certain insulation tests to make sure that the insulation is in good condition. These insulation tests have been standardized by the standardization rules of the American Institute of Electrical Engineers.

**Refer to the JOURNAL for March 1918 for further information concerning the value of test voltages on old apparatus. The practice of a number of operating companies is given in an article entitled "Periodical Insulation Tests," which appears in that number.

ommended for this purpose. The value of this resistance should be such as to prevent enough short-circuit current from flowing to do damage to the system and, on the other hand, it should be large enough to allow the *IR* drop to attain an excessive value even under the worst possible conditions. Its exact value is difficult to fix. A safe rule to follow is to make the ground resistance as small as possible without introducing undue difficulties on account of the short-circuit current. The difficulties due to the short-circuit current are:— first, the possibility of distorting the windings of the generator from the excessive current; and second, the difficulties contingent upon the breaking of the short-circuit arcs in the circuit breakers. With a properly designed generator winding the first of these difficulties need not be seriously considered. Generator windings should be braced sufficiently so that the strains due to short-circuits will do no injury. This is necessary from the consideration that short-circuits on generators may be from phase to phase, and in that event no current would pass through the grounding resistance even if it were present; hence generators should stand successfully a short-circuit from phase to phase, and when so designed there is, of course, nothing to apprehend when the short-circuit is between a phase and neutral.

The easing off of the short-circuit strains on the switches is sometimes considered in fixing the value of the grounding resistance. Here again, however, the consideration that switches must be so designed that they will stand successfully a phase to phase short-circuit makes the value of the grounding resistance of no moment. In the phase to phase short-circuit, the grounding resistance plays no part, and the switches must, of course, be able to withstand short-circuits of this nature.

The specific remedy to the problem of protecting generators and other parts of the electric circuit against excessive short-circuit currents is the use of reactances. These reactances may be placed in the generator circuits, in the feeder circuits or between sections of bus-bars. The location of reactances in the feeder circuits is generally considered preferable. However, owing to the fact that feeder circuits are usually more numerous than the generators, the cost of installing reactances on all feeder circuits is sometimes prohibitive. The alternative of installing reactances in the generator circuits is, therefore, often used. The disadvantage of this location is, that a short-circuit on any feeder lowers the voltage of the entire system, on account of the drop through the generator reactances, while if the reactances are placed in the feeder circuits, the excessive voltage drop occurs on the affected feeder only, and does not extend to any great degree, to the feeders which are not in trouble. From this consideration therefore, the location of the reactances in the feeder circuits is desirable, and other locations should be considered only when questions of cost become controlling. The use of sectionalizing reactances in the bus-bars is a compromise between the use of feeder and generator reactances. When bus-bars sectionalizing reactances are used, a short-circuit on a given feeder will be fed directly from one or more of the generators in service, while the current from the other generators is taken through one or more of these sectionalizing reactances. The benefit due to reducing the current fed into the short-circuit is, therefore, only partially obtained. The whole question of reactances, their best location, the value to be used, etc. is a large one.*

The question often arises, how is a delta three—phase system to be grounded? The neutral of the delta system, of course comes in the center of the delta, and there is no electrical connection at this point which may be used to connect to ground. When it becomes necessary to ground a delta system, a ground has to be derived; this may conveniently be done by the use of transformers. Three single-phase transformers may be used for this purpose, one end of each transformer being connected to a point of the delta and the free ends connected together to form the neutral of the delta system. In this case, however, the secondaries of the transformer must be connected in delta in order to make the neutral point a stable one. If the secondaries of the transformers are not connected in delta, the neutral becomes unstable and under no condition will the bank of transformers pass any more current than just sufficient to excite the transformers. If the secondaries are connected in delta, the neutral point is rigidly fixed and the grounding transformer bank will pass an amount of ground current, depending upon the short-circuit characteristic of the transformers.

Another method of deriving a ground on a delta system is to use a three-phase transformer wherein the magnetic circuits of the various phases are interlinked. If the magnetic circuits are interlinked, it is not necessary to use the delta connected secondaries in order to obtain stability of the neutral point; in fact no secondary winding is necessary, unless the transformer is to carry load as well as furnish neutral point. Still another method is to use three-phase transformers with the primary in star and the secondaries in delta, in which case the three-phase transformer acts, as do the single-phase transformers mentioned above. In this case it does not matter whether the transformer is designed with interlinking magnetic circuits or not.

In case a neutral is derived, the question of current carrying capacity in the transformers must be considered. The grounding transformers should, of course, be capable of carrying all of the current which must pass to ground, without damaging the transformers. No general rule can be given to cover this point, but the same consideration should govern as in

*For further information on this subject, see "Protection against Short-Circuits" by P. M. Lincoln in the JOURNAL for Dec. 1913, p. 1217. "Protection of Electrical Equipment against Electrical Surges" by P. M. Lincoln in the JOURNAL for July 1910, p. 575. "The Effect of Limiting Reactances on the Application of Oil Circuit Breakers" by J. N. Mahoney in the JOURNAL for April 1914, p. 200. "Oil Circuit Breakers and Their Application" by J. B. Mac Neill in the JOURNAL for Aug. 1916, p. 364 and Nov. 1916, p. 547.

the selection of the value of the resistance to insert in the ground of a system where the neutral connection is already present. In any event the transformer capacity must be large, relative to the capacity of the circuit. In the case of low voltage secondary circuits of limited capacity, where the cost of grounding transformers would exceed the benefits derived, a spark gap may be placed between one of the terminals and ground on a delta or between the neutral and ground on a star connected winding, in lieu of grounding.

In considering the grounding of neutrals, the question often arises as to whether it is advisable to install more than one ground connection. So far as the question of safety to the system and the apparatus on it is concerned the more points that are grounded the better. Safety for the apparatus, however, is not the only thing to consider. When two or more neutrals on the same system are grounded, there is apt to be an exchange of current through the ground between these points. These circulating currents are usually high frequency, and often render telephone and telegraph circuits in the neighborhood inoperative. If it were not for such circulating currents a multiplicity of grounds on a given system would be desirable but the possibility of circulating currents usually makes it desirable to adhere to a single ground. The best location for the ground is usually the power plant. When two or more power plants in different locations are operated in parallel the best place to ground is usually the larger of the two plants. If there is no danger of trouble from circulating currents, both plants may be grounded. The disadvantage of having a ground at a single plant only is that its protection is eliminated on a part of the system whenever the two plants are separated. The separation of the two plants by the operation of circuit breakers in case of trouble, may cause the protection of the ground to be eliminated at just the time when it is most needed. In such a case, therefore, the double ground is desirable and is recommended provided it does not cause trouble from circulating currents.

The question has been sometimes raised as to whether or not it is desirable to ground the neutral of an important motor rather than the neutral at the power plant. This question is governed by the same considerations as govern the grounding of the neutrals of two separate power plants. If the motor is considered more important than the power plant, it may be advisable to ground the system at the motor instead of at the power plant. The best remedy in such a case is a ground at both places provided no trouble is experienced due to the circulation of ground currents.

The operator should bear in mind that grounds on one side of a bank of transformers do not give protection against surges which may occur on the other side of this bank. The writer has in mind the case of a high-voltage transmission system in which the high voltage lines were operated with a solidly grounded neutral. In this case, however, the generators were left ungrounded and on one occasion, when an accidental ground occured on the windings of one of the generators, the surges set up were so severe that not only was the generator wherein the trouble occured, burned out, but it also carried with it another generator running in parallel with it. In this case no ground had been provided to take care of surges on the generator windings, although the high-tension side of the transformers to which these generators were connected, was thoroughly grounded. A ground should have been provided on the generator windings, as well as on the high-tension side of the system. The ground on the high-tension side, in this case, gave no protection whatever from surges which were set up on the generator side of the transformers. This is something that should be carefully looked after every time power is passed through transformer banks, and care should be taken that both sides of the banks are thoroughly grounded.

This resume on protection of electric circuits would not be complete without pointing out the inherent advantages of transformer insulation over that of generators and motors. The conductors of generators and motors are buried in slots and insulated therefrom by insulation which must necessarily be always kept dry. The thickness of insulation is limited by the slot dimensions, and considerations of cost necessarily keep the slot size to a minimum value. Transformers, on the other hand, are usually immersed in oil and the space allowed for insulation is not limited as it is in generators and motors. As a consequence the insulation of transformers is invariably much better than can possibly be expected on rotating apparatus. This is the main reason why the writer has always advocated in general, the use of rotary converters rather than motor generators, where it was necessary to obtain direct current from an alternating source. The insulation of the transformers of a rotary converter set is always sturdier than that of the motor in the motor-generator set, and as a consequence the integrity of the converter is usually much higher than that of the motor-generator.

In closing the writer wishes to emphasize once more the necessity for "eternal vigilance". Only by the exercise of continual care and careful supervision can the operator of electrical apparatus hope to maintain his equipment constantly in proper running condition.

Methods of Balancing Rotors

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WITH the rapid adoption of turbine-driven machinery and the increased speeds at which it is now considered safe to run almost all classes of machines, the elimination of vibration becomes more and more important. With this general increase in speed, not only have stresses increased, but the tendency towards vibration has also become much greater, while the intensity of vibration and consequently the damaging effects which result from it, have grown in proportion. Obviously the greater the speed at which a machine is run the less will be the amount of out-of-balance necessary to set it vibrating and the more intense or violent will be the vibration. Again, the more intense the vibration the greater will be the tendency toward the loosening of parts, opening out of bearings,

FIG. 1—STATIC BALANCING APPARATUS
For flywheels of large diameter.

springing out of foundations, etc. It becomes therefore a matter of great importance that the accuracy of the balance of rotors be such that they operate without excessive vibrations.

Two states of balance must be distinguished, static or standing balance and dynamic or running balance. Static balance insures dynamic balance in the case of thin discs but not with long drums such as are usual in practically all high speed generators and motors.

STATIC BALANCE

The standard method of obtaining static balance by means of rolling the body supported by its shaft on a set of parallel straight edges is well known and gives excellent results for the larger class of rotating machinery. Special apparatus is necessary, however, in some cases to obtain an accurate static balance. The fixture shown in Fig. 1 is sometimes called the umbrella balance and consists of a three-quarter inch hardened steel ball mounted in a hardened and ground cup of slightly larger diameter. The cup is supported on the top of a pedestal. The rotor is mounted on a hollow mandrel which has a cup similar to the pedestal at the exact center and at a height that will bring the center of gravity of the rotor slightly below the point of support. When the mandrel in the rotor is mounted so that the steel ball carries the entire weight and is in exact mechanical center, it is only necessary to level up the rotor to obtain a static balance. This apparatus is extremely sensitive and gives excellent results.

A highly sensitive and accurate apparatus is used to give rotors, made up of several discs, a running balance by balancing each disc separately. This machine, shown in Fig. 3, consists of a turntable mounted so as to rotate on a beam, which in turn is supported by means of two knife edges which rest in self-aligning

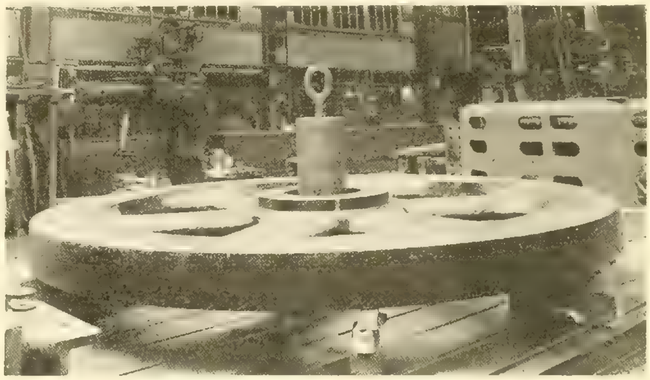


FIG. 2—FLYWHEEL ON TEST FLOOR
Having static balancing apparatus of Fig. 1 attached and ready for balancing.

sockets upon the supporting base. The amount of the hanging counterweight is adjusted so that the center of gravity is just below the plane of the knife edges and will oscillate slowly. When the turntable supporting the part to be balanced stays in the position of a horizontal plane during a complete revolution, the part is in static balance. The horizontal position of the table is determined by the pointer being made to oscillate equally on each side of the zero point, thus eliminating the starting friction of the knife edges.

Still another machine for placing rotors in static balance is shown in Fig. 5. It consists of a pair of large wheels mounted on ball or roller bearings with a smaller wheel at the top adjustable so that shafts of different diameters can be used. The piece to be balanced is pressed on an arbor and the arbor placed on the top of the large wheel resting slightly against the smaller one. The adjustment is such that the point of contact will be about one degree from the vertical center line passing through the center of the large wheel.

This will allow the shaft to rotate easily without any wedging action and with a minimum friction. Where rotors have their own shafts this machine is very convenient to use and gives a reliable and accurate static balance without which no dynamic balance is possible.

DYNAMIC BALANCE

The satisfactory operation of any rotor is by no means assured when it has been placed in perfect static balance. There still remains the problem of securing running or dynamic balance. In Fig. 4 is shown a rotor with two weights n and m attached so that $mr = nR$. Under these conditions it is apparent that the rotor while in static balance will be acted upon by a centrifugal force mr and a corresponding one nR. As these forces are not in line with one another, the net result, as the piece revolves, is a revolving couple or so called centrifugal couple which gives rise to vibration of the rotor.

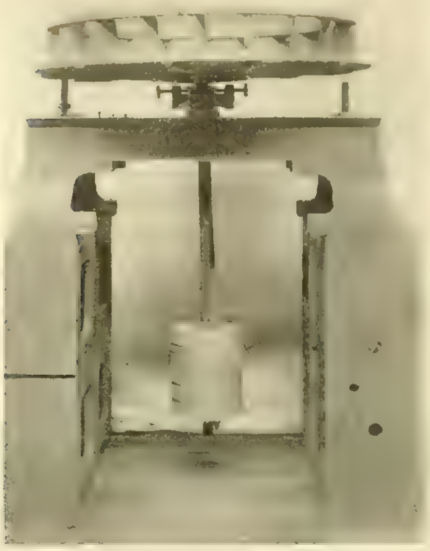


FIG. 3—STATIC BALANCING MACHINE
For disc rotors.

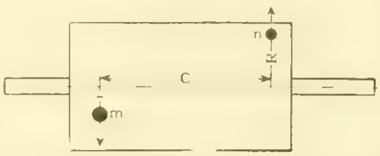


FIG. 4—MOMENT DIAGRAM OF AN UNBALANCED ROTOR

The correction of this condition is simple and requires only the addition of two counterweights equal in weight and at the same radial distance from axis or lesser in weight and at a greater radial distance in the same plane, or a centrifugal couple may be added in any convenient place so that it be equal to the unbalancing force. For $mr = nR$, therefore, the *Force* $= 2mrC$. It is desirable to keep the radial distance R and the axial distance C as large as possible so that the added weights may be small.

The method that has been most generally used for finding the amount and location for placing the required weights is to rotate the body either in its own bearings or a special set of bearings carried on flexible springs to get an exaggerated vibration. When full speed has been reached a marker of some kind is held against the shaft:—a pencil used for marking china or glass is the best one for this purpose. The amount of vibration is noted and the rotor is shut down to observe the position of the marks. The high spot thus obtained does not occur directly in line with the heavy spot in the rotor but lags behind from 0 to 90 degrees depending on the construction of the particular rotor. With most turbine rotors it will be found 30 to 50 degrees behind the heavy spot. Weights are added as indicated by the marks and another trial is made and continued in the same way until the vibration has been eliminated. When it is possible to rotate the body in either direction the exact heavy spot may be found more easily by marking the shaft carefully in each direction of rotation and trying a position for weights either half way between these marks or 180 degrees away from this half way position.

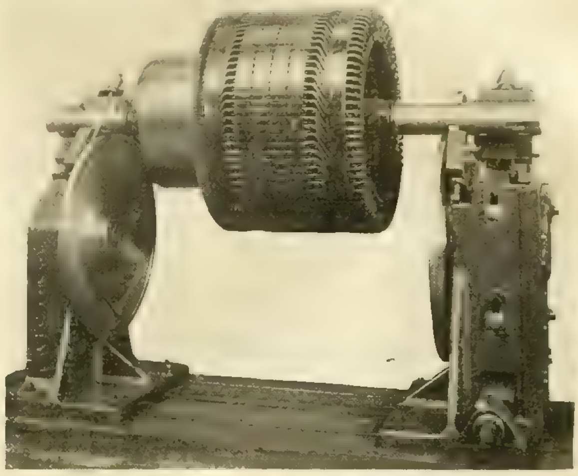


FIG. 5—STATIC BALANCING MACHINE

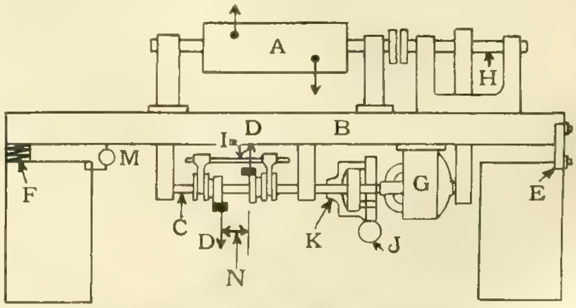


FIG. 6—DYNAMIC BALANCING MACHINE

A—Rotor; *B*—Vibrating bed; *C*—Splined shaft carrying compensating weights *DD*; *E*—Hinge; *F*—Spring support; *G*—Motor; *H*—Head shaft; *I*—Right and left hand screw; *J*—Worm; *K*—Internal gear of planetary drive; *M*—Vibration indicator; and *N*—Variable distance.

It is apparent that the process of balancing is neither rapid nor easy, as a good many trials must be made for the purpose of verification, etc. Also bodies such as high speed electrical machines take a good deal of time in coming up to speed and slowing down.

A rotating body in balance at one speed is also in balance at all other speeds, although unbalanced bodies

will have a speed at which they synchronize with the natural period of vibration of their supports. When this is reached a more violent vibration is noticed than either above or below this particular speed.

A machine made to indicate both the amount and angular position of the unbalanced couple has been in use for a comparatively short time and gives accurate and rapid results. In principle it is a rigid horizontal bed hinged at one end and free to vibrate in one plane only at the other end, as shown in Figs. 6 and 7. The bed resembles a lathe bed and is hinged at one end by a support of light steel plate flexible enough to allow the bed to vibrate easily. The other end is supported by a set of steel springs whose natural period of vibration corresponds to the speed at which it is desired to balance all rotors. This speed occurs for this machine at about 500 r.p.m. The rotor to be balanced is mounted on top of the bed in half bearings babbitted and fitted with a lubricating device. It is coupled to the driving mechanism by a semiflexible spring coupling. A set of compensating weights are hung underneath the bed so arranged that when pushed together they are in perfect balance but are capable of being moved apart by means of a screw and hand wheel, in which case the overhanging tips become a set of weights and the distance apart they are moved determines the amount of the centrifugal couple. The machine, Fig. 7, has two sets of compensating weights which can be used separately or together. The picture shows one set closed and in balance and the other set a short distance apart and therefore unbalanced a certain amount. The driving motor is suspended from the hinged end of the bed and is connected mechanically by means of spiral bevel gears to the mechanism that drives the rotor. The other end of the driving motor is connected to the compensating weights through a planetary gear which drives them at exactly the same speed as the rotor.

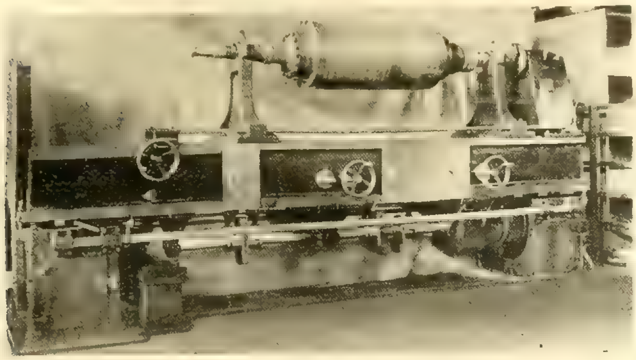


FIG. 7—CARWEN BALANCING MACHINE
Built by The Carlson-Wenstrom Co., of Philadelphia.

The detail of the compensating weights can be seen in Fig. 8. The hand wheel is connected by a gear to a screw supporting a fork which rides in a slot turned in each weight. When the hand wheel is turned, the right and left hand thread of the screw forces the weights apart. The dials shown record the distance moved, being calibrated in inch-pounds for convenience. The hand wheel at the extreme right, Fig. 7, operates through a set of gears the internal gear of the planetary drive and through this, the angle of the weights may be shifted with respect to the rotor, while running. The dial indicator, which measures the amount of vibration, is fastened on the end of the machine opposite the hinge so as to obtain the maximum vibration.

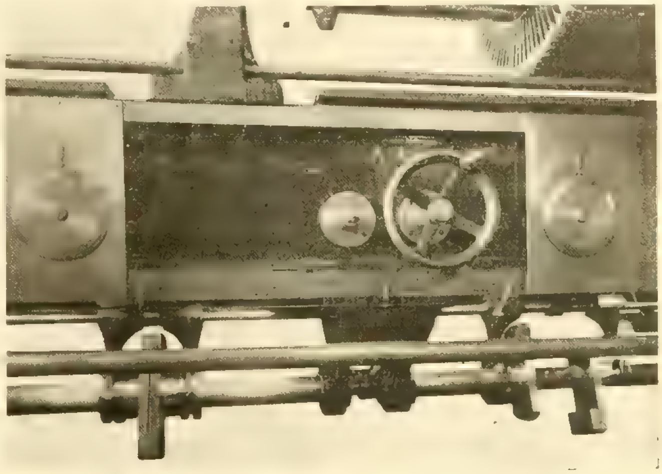


FIG. 8—DETAILS OF CARWEN BALANCING MACHINE

The operation of balancing any rotor has been reduced to a very simple process for machines within the capacity of the dynamic balancing machine. The machine shown in Fig. 7 has a capacity of 14 000 pounds.

First it is very important that a good static balance be secured. This may be done by any of the methods which fit the rotor in question and gives sufficiently accurate results. Then the rotor is placed in the balancing machine and coupled up to the driving head. The compensating weights are all set at zero so that the only unbalancing couple will be that in the rotor. The motor is then started up and brought to the speed of maximum vibration as shown by the indicator:—this will be about 500 r.p.m. but small adjustments of the speed by means of the rheostat may be necessary to get the exact point. Offset the weights slightly and shift the angle until the point of greatest vibration is found, that being more apparent than the least vibration. Then shift the angle back 180 degrees and vary the amount of compensating weight until the

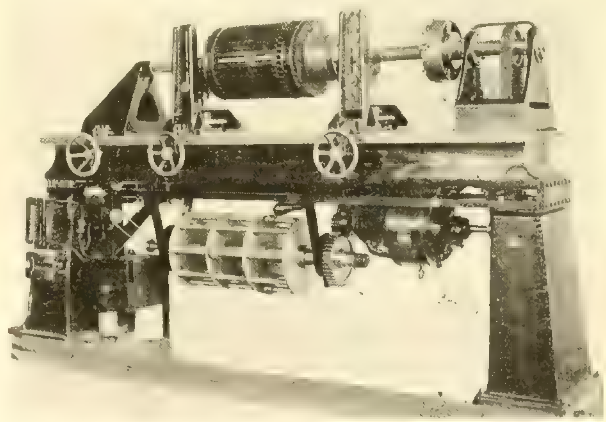


FIG. 9—AKIMOFF BALANCING MACHINE

vibration is very small. A final adjustment of the angle and weights will now bring the machine to a point of perfect smoothness.

To transfer the couple to the rotor being balanced, turn the rotating parts so that the weights are in a vertical plane, this is indicated by a mark on the weights which will stand opposite a pointer on the frame. Now the adjustment required in inch-squared-pounds is read on the dial. On all rotors are two planes at right angles to the axis with some means of attaching weights at a known radius. Also these places are a known distance apart. Assuming that, in a particular rotor, the distance between weights is 20 inches and the radius is 10 inches, also the dial reading was 1000. Then the total weight required is $1000 \div (20 \times 10) = 5$ pounds. Therefore the rotor requires a 2.5 pound weight at each end 180 degrees apart and in the same indicated position as the compensating weights.

It is quite possible to add the required weights to the rotor, reset the compensating weights to zero and check the balance by running again, but as a general rule this is unnecessary as the results obtained are sufficiently reliable to eliminate this operation.

An earlier machine made by Akimoff is shown in Fig. 9. The method of shifting the compensating weights is not as good as in the later machines. It consists in screwing out a pair of rods in the cage seen underneath the bed. A piece of rubber is held against the toothed ring seen on the outside of the hollow bar carrying the rod. This is connected to the rod by means of a screw and rack, thus when the rubber turns the ring it forces out a pair of rods in the opposite direction 180 degrees apart and produces the compensating weight. By moving axially along the balancing cage any angle may be obtained by choosing the proper set of rods. As this machine has a capacity of 2500 pounds only, the rotors may be carried in rollers with ball bearings and lined up by means of the centers in the shaft. The driving mechanism is a standard lathe chuck carefully balanced. After setting up it is a very easy matter to check the shaft to find if it runs true. This method of handling allows the rotor to be put in and taken out very quickly, but the handling of the compensating weight is rather slow.

Industrial Training-A War Measure

C. S. Coler
Educational Dept.,
Westinghouse Electric & Mfg. Company

The WAR has brought us as a nation face to face with the problem of getting more work done with less total available man power. To complicate the problem, the relative importance and amount of different kinds of work has changed, causing a shifting of workers which has resulted in many positions being filled by those unfamiliar with the work. In addition to this the increased demand for workers has drawn into industry many who have had no previous industrial experience.

The apparent man power needed in industry today is great compared with the true man power which should be needed;—or to state the matter differently, with our available man power we could more quickly complete the extra work, which is required for winning the war, if every one in industry were better prepared for his work. The national problem in industry today is not so much lack of men as low man "power-factor." As time goes on this condition would logically improve slowly but at present, time is a very important factor. A great improvement can be made rapidly by intensive training. What the Army and Navy are doing for those who enter their service, industry must do for those who enter its organizations.

The function of such industrial training is two fold—to prepare new employes for their specific work in the industry, and to aid those already in the industry to rise through promotion based on the application of greater knowledge and skill to their work. Intensive training in no way takes the place of the broader and more thorough trades courses which have been conducted in the past. It is intended only to acquaint employes quickly with the specific details of new work which they may be called upon to perform. The principle is economically sound as it benefits the industry, the employe and the nation.

THE VESTIBULE SCHOOL

Where the rate of taking on new employes for work of a somewhat similar nature warrants, the vestibule school offers decided advantages for intensive training over the older methods of instruction "on the job". A separate training room or section is equipped with standard tools and supplied with work of various kinds similar to that on which the employes will be placed after receiving instruction. The instructor in charge of the training section should be thoroughly familiar with the various phases of the work to be done and should possess the ability to impart his knowledge and skill to others.

The employe taking up new work in the industry, through the vestibule school, receives a special instruction period rate during the training period. Intensive instruction is provided, not only about the work itself but about other matters relating to it such as blue print reading, shop rules and discipline, the system of wage payment, materials, etc. The working conditions in the training section are less liable to cause nervousness, particularly with women employes, and that first period of

discouragement, which usually comes to those taking up new work, can be overcome by special attention, under conditions which do not expose the learner to observa-

FIG. 1—TRAINING SECTION FOR INTENSIVE INSTRUCTION ON MACHINE-TOOL OPERATION

Instruction is given on bench work, assembling, drill press, milling machine, screw machine, grinder, shaper and lathe. Particular attention is given to the size and kinds of work on which women employes are placed and machines are equipped with modern safety devices. The length of instruction period is from two days to four weeks depending on the operation and the aptitude of the operator. Effort is made to train the operator for the work to which he or she is best adapted. Some of the best workers are slow to learn; but if a trial demonstrates a lack of natural mechanical ability, the operator is shifted to some other line of work.

tion and ridicule by those who are more familiar with the work. The instructor can aid in placing the new employes on the proper work at the proper wage. The instruction does not tie up work on the floor which is being carried through in the normal process of manufacture, and the time ordinarily lost on machine tools in finding new operators and acquainting them with the work is reduced by supplying the need from the reservoir provided by the training section.

TRAINING FOR PROMOTION

Those employes who wish to prepare for more important work in the industry may be placed in the school

FIG. 2—TRAINING SECTION FOR TRACING AND MECHANICAL DRAWING

Training in this class covers lettering, tracing, mechanical drawing, mathematics and applied arithmetic. Minimum requirements for entrance—two years of high school. Length of instruction period from four to six weeks. Those who show particular aptitude for this work after completing the instruction period are given further instruction, on part time, in detail drawing.

either on full time or part time for intensive training. This minimizes the loss to the industry and to the employe due to the change of work and opens up a path for advancement to many in the industry who are capable of filling more responsible positions but who under the old system could not afford to change their work.

FIG. 3 STENOGRAPHIC TRAINING SECTION

Instruction covers the use and spelling of technical words, operation of the dictaphone, company system of handling correspondence, filing systems, etc. Requirements for entrance—completion of commercial high-school course or business college. Length of instruction period from three to six weeks.

Through intensive training the office boy, if he qualifies, can go to school several hours a week to learn tracing or to prepare for clerical work, machine tool operation or electrical work, according to his aptitude and desires. The introduction of intensive methods of training has been rather slow in the past, just as the use of high-speed tool steel and other innovations have been slow in their adoption. The war

FIG. 4—TRAINING SECTION FOR ELECTRICAL WORK

Instruction is given on the winding and insulating of coils and other electrical work such as soldering, mica building, inspecting materials, etc. Length of instruction period from two days to four weeks.

has accelerated the work of intensive training and once established, its advantages are so apparent that training sections may be recognized as being just as necessary to industry after the war as they are at the present time.

The Use of Graphic Instruments

In Improving the Operation of Electrical Apparatus and Reducing Cost of Maintenance

J. H. Overpeck

IMPROVEMENTS and changes are constantly being made in the types of mills and machinery used to produce steel so that in new mills motors are frequently used on certain applications in which the nature of the power cycle has not previously been worked out. In order that the motor may be utilized to the best advantage in such cases, it has been found advisable to make use of graphic instruments having high paper speed to determine whether or not the best operation is being obtained and secondly if a modification of the control or a different design of motor would perform the work easier and with less abuse to the motor and the control. During the present time this is particularly true in view of the fact that many mills which were installed just previous to the war, are now required to roll material entirely different from that for which the mill was designed.

When armature changes are frequent, the cost of maintenance becomes heavy but the delay encountered in making the repairs is of still greater importance. In order to ferret out all cases where particular trouble is encountered, it has been found desirable to record the repairs made, with a summary for the electrical superintendent at the end of each month, so that the applications giving the most trouble can be quickly brought to his attention.

Motor repair records can be conveniently made in some such form as that shown in Table I, using a separate sheet for each line of motors. Each application in the mill is entered in a separate column on one inspector's sheet when repairs are made for the first time, after which all repairs made on this application will be noted in this column. Thus if there are twelve motors of one frame size under one inspector, there will be twelve columns under this heading and the application of each will be entered at the bottom.

In Table I, the repairs or failures are divided, as shown, into four general classes, armature and commutator, field, brush and bearing troubles, each of which is subdivided as far as is deemed advisable. This record should be carefully kept and the places where failures occur noted accurately; distinguishing, for example, between a ground on a commutating pole and one on a series field coil or a shunt field coil. The value of the reports will depend upon the accuracy with which these reports are classified.

After the inspectors' reports have been completed, little time is required to transfer the records of failures to the various inspectors' sheets. The record should be kept continuously and at regular intervals the sheets should be totaled and the records transferred to a large motor sheet which has the total number of applications

TABLE I—ELECTRICAL INSPECTOR'S REPAIR RECORD

________ Steel Co. ________ Works

Inspector ________ From ________ 1918, to ________ 1918 ________ Plant

Type and No.	Frame A	Frame B	Frame C	Frame D	Frame E	Frame F	Frame G	Frame H	Frame I	Total	Total Failures due to one cause
Total Motors in Mill	5	18	10	35	12	8	16	8	6		
Application No.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5		
Series or Compound	S S S S S	S S S S S	S S C C S	S S S C S	C C C S S	C C S S C	C C C C C	C C C C C	C C C C C		
Armature Ground											
" Short											
" Open											
Broken Banding											
Comm. Ground											
" Short											
" Undercut											
" Turned											
Ser. Fld. Ground											
" " Open											
" " Short											
Comm. Fld. Ground											
" " Short											
" " Open											
Shunt Fld. Ground											
" " Short											
" " Open											
Replaced Brushes											
Brush Holder Trouble											
Bearing Trouble											
Total											
% Total Failures*—Same Fr. No.											
% Motors—Same Fr. No.—Failures											
Application											

* All percentages should be figured on an annual basis

of any one line of motors. Such a large total sheet would be of the same general form as the individual inspectors' sheets, with some additional columns. These are obtained from the following analysis:—

1—The total number of failures on any one application should be compared with the total failures on the motors of the same frame. This will indicate whether any one motor is giving more trouble than duplicate motors on other applications through the mill.

2—The total number of motors of any one frame which have failures compared to the total number of duplicate motors in the mill. This will indicate whether single motors or all motors of one frame size are giving trouble.

3—The total number of failures due to any one cause on each application compared with the total failures on that same application. This will indicate at once where the trouble is and taken with No. 1 give an immediate check on every motor in the mill.

4—The total number of failures due to any one cause on all motors of the same size compared to the total number of failures due to all causes on the same motors. This will indicate any weakness or general defect in all motors of the same size.

5—The total number of failures due to any one cause on all motors of the line throughout the mill compared to the total of failures due to all causes on the same. This will indicate any weakness or general defect in all motors of the line.

6—The total number of the motors which have failed compared to the total number of motors of the same line throughout the mill. This will indicate the extent to which repairs are necessary throughout the mill.

All of the above should be figured on a percentage basis. Table II shows such a sheet worked out for a steel plant. An analysis of Table II shows that the most trouble is experienced with frame *D* of which 111 percent require repairs annually, 70 percent of the failures being caused by commutator trouble and 14 percent by roasted armatures. Naturally the superintendent will first investigate the operations to which this size of motor is applied, after which frame *C* will be investigated. The column of percent total failures shows that 54 percent of all motor repairs are caused by commutator trouble and 21 percent by roasted armatures, other troubles being relatively unimportant. Both of these causes indicate faulty application, rather than any inherent defects in the motors themselves. Commutation trouble is very often due to improper adjustment of control or unusual starting and braking conditions. A graphic instrument would clearly indicate the

TABLE II—MOTOR FAILURES

Period Observed April 26, 1918, to June 26, 1918.

Type / Total No. of Motors	Frame A S=[illegible] C=0				Total	% Total Failure	% Total Motors 1-year basis
Application Number	1	2	3	4			
Series or compound	S	S	S	S			
Arm roasted (overload)	2	1	1		4	80	24
Arm ground							
Arm short				1	1	20	6
Broken banding							
Commutator trouble							
Series field ground							
Bearing trouble							
Number of failures	2	1	1	1	5		
Total—1 year basis					30	100	30.6
Application	No. 6 Jib Crane	No. 10 Jib Crane	No. 1 Jib Crane	Blooming Mill Rolls			

Type / Total No. of Motors	Frame B S=45 C=5	Total	% Total Failure	Total Motors 1-year basis
Application Number	1			
Series or compound	S			
Commutator trouble	1	1	100	12
Number of failures	1	1		
Total—1 year basis		6	100	12
Application	Open Hearth Cranes			

Type / Total No. of Motors	Frame C S=26 C=0		Total	% Total Failure	Total Motors 1-year basis
Application Number	1	2			
Series or compound	S	S			
Commutator trouble		1	1	50	23
Series field ground	1		1	50	23
Number of failures	1	1	2		
Total—1 year basis			12	100	46
Application	No. 3 Charging Machine	No. 2 Charging Crane			

Type / Total No. of Motors	Frame D S=[illegible] C=6												Total	% Total Failures	% Total Motors 1-year basis
Application Number	1	2	3	4	5	6	7	8	9	10	11	12			
Series or compound	S	S	S	S	S	S	S	S	S	S	C	S			
Arm roasted (overload)							1		1				2	14	16
Arm ground	1												1	7	8
Broken banding					1								1	7	8
Commutator trouble	1	1	1	1		1		1		2	1	1	10	70	80
Number of failures	2	1	1	1	1	1	1	1	1	2	1	1	14		
Total—1 year basis													84	100	111
Application	No. 1 Pit Crane	Pot Car	Bloom Storage Crane	No. 2 Pit Crane	Bloom Storage Crane	No. 3 Pit Crane	Blooming Mill Crane	No. 1 Finishing Mill Yard Crane	Open Hearth Cranes	No. 2 Pot Car	Shear Run	Open Hearth Cranes			

Type / Total No. of Motors	Frame E S=40 C=7	Total	% Total Failures	Total Motors 1-year basis
Application Number	1			
Series or compound	S			
Arm ground	1	1	100	12.7
Number of failures	1	1		
Total—1 year basis		6	100	12.7
Application	No. 1 Bloom Mill Crane			

Type / Total No. of Motors	Frame F S=[illegible] C=25					Total	% Total Failures	% Total Motors 1-year basis
Application Number	1	2	3	4	5			
Series or compound	S	S	S	C	S			
Broken banding					1	1	20	6.5
Commutator trouble	1	1		1		3	60	19
Bearing trouble			1			1	20	6.5
Number of failures	1	1	1	1	1	5		
Total—1 year basis						30	100	32
Application	Blooming Mill Crane	Open Hearth Cranes	No. 2 Mill Crane Hoist	Blooming Mill Rolls	Open Hearth Cranes			

Type / Total No. of Motors	Frame G S=10 C=0	Frame H S=5 C=0
Application	No Failures During Period	No Failures During Period

Type / Total No. of Motors	Total S=302 C=43	% Total Failures	Total Motors 1-year basis
Arm roasted (overload)	6	21	9
Arm ground	2	7	3
Arm short	1	3.5	1.5
Broken banding	2	7	3
Commutator trouble	15	54	22
Series field ground	1	3.5	1.5
Bearing trouble	1	3.5	1.5
Number of failures	28		
Total—1 year basis	168	100	41.5

relation between the starting, load and braking current. If unequal peaks are obtained, the necessary adjustment of resistors can be made to relieve the motor.

The cycle of operation of the majority of motors in a steel plant is a matter of seconds, and in order to get a proper conception of what is occuring, it is necessary to use graphic instruments having high paper speed, so that the operation of a few seconds is extended over several inches of paper. In the case of direct-current motors a millivoltmeter for reading the load current and a voltmeter for indicating speed are needed. The latter is connected to the terminals of a magneto and calibrated in r. p. m. The majority of mill applications are reversing and a zero center meter is preferable.

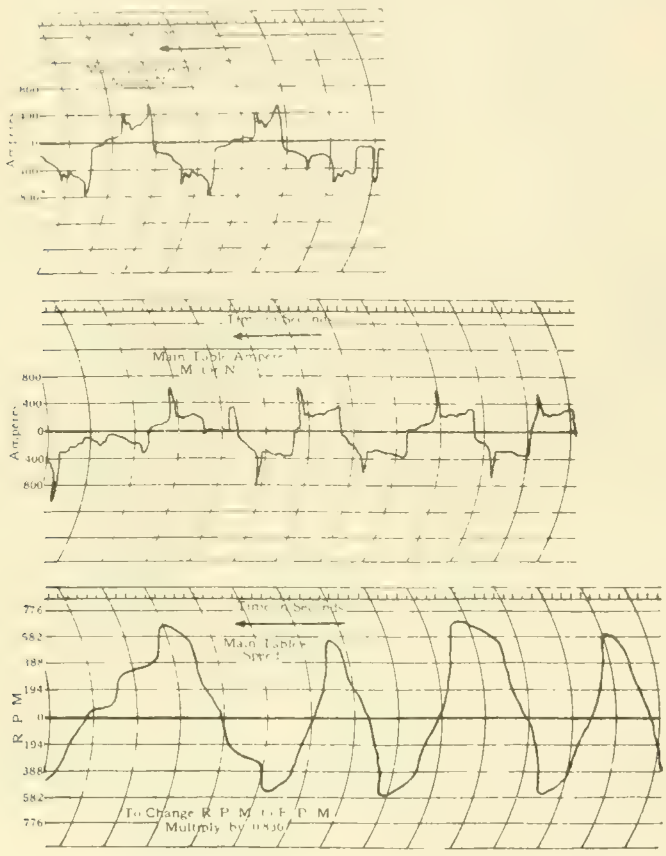


FIG. 1—GRAPHIC LOAD AND SPEED CURVES OF MAIN TABLE DRIVE
Of a typical blooming mill. Showing sluggish acceleration.

As a typical analysis of such conditions, the operators in a mill complained that a main table drive for a reversing blooming mill was sluggish, requiring too long to accelerate. The table was driven by two compound motors in parallel and it was believed that one motor was carrying more than its share of the load. Graphic charts were taken on both motors of load current and speed, as shown in Fig. 1. A clock attachment on the two meters marked seconds as shown. Such an attachment helps to synchronize the charts. The speed curve showed a slow acceleration and the variation in current peaks on the two motors was enough to show why one motor was warmer than the other. The resistance notches were adjusted until the operation of both was as shown in Fig. 2. Thermometer readings taken after this was done, indicated the same temperature rise in the two motors and the steeper speed curves show that an increased speed of operation obtained.

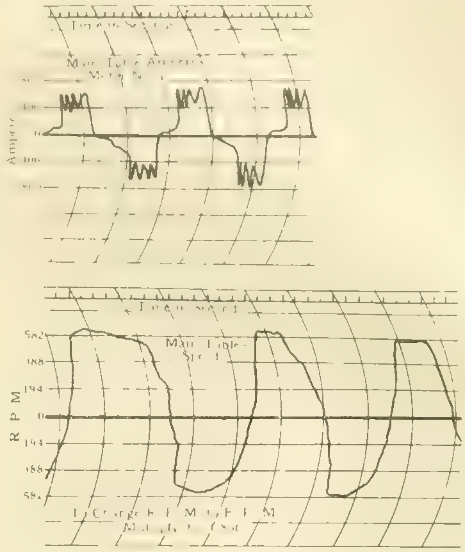


FIG. 2—GRAPHIC CURRENT AND SPEED CURVES OF MAIN TABLE DRIVE
After adjustment of the resistance notches to give increased speed of operation.

An analysis of the curve was next made and the root mean square current was calculated over the working cycle in the following manner. The curve was divided into second periods as shown in Fig. 3 the current value at the middle point of each period was squared and all the results over the cycle were added. The sum was divided by the number of values taken and the square root of the quotient taken. This value represents the equivalent continuous current over the cycle taken. It was found that this value exceeded the continuous current rating of the motors. Hence a ventilating system was laid out and since it was put in operation the increased rate of acceleration has been maintained with very little expense.

On a blooming mill screw down, the operators complained they could not set the screw accurately without trying several times. A test was made and at once the trouble was seen in the low dynamic braking peak.

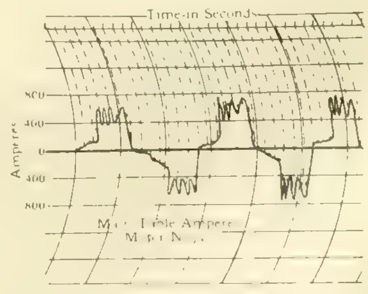


FIG. 3—ANALYSIS OF LOAD CURVE OF FIG. 2
To find the r.m.s. current over the working cycle.

Part of the braking resistance was cut out until a quick accurate stop was possible. The speed curve showed the actual increased rate of deceleration.

The motor inspectors in one mill complained that they were having trouble with a number of controllers

on light auxiliaries. The controller required new contacts two or three times a week. It was observed that some one or two switches were burning badly. Some times these were reversing switches and sometimes resistance contactors.

Tests were taken of all applications which were causing complaint, as follows:—With the graphic ammeter in circuit a few operating cycles were recorded. It was found the motors were taking very high peaks and that these were irregular. In some cases the first contactor would cut out nearly all the resistance, in some cases the second. The resistance steps were then adjusted, some being increased and others decreased until the acceleration peaks were regular and equal and of the right value for the motors under test. This would invariably bring a complaint from the mill operators that the application was slow. As could be expected the controllers were now behaving normally. Keeping the acceleration peaks equal and the control in adjustment the resistance steps were gradually decreased and the current peaks increased until the operators were satisfied. The contactors had now begun to crack very sharply again. A few operating cycles were again recorded on the meters. This test was repeated on every application of which complaint was made.

The analysis plainly indicated that the applications were undermotored. The controllers were of the proper size for the motors, provided the motors were not too heavily overloaded. The operators had complained of slow operation and the starting resistance had been short-circuited in some cases without considering the effect on the motors and the rest of control. In some cases the motors were carrying four and five times normal starting current and it would be expected that the controllers would burn badly. In some other cases the high peaks were caused by plugging series motors after they had come up to speed on very light friction loads. It was recommended that some of the series motors be replaced by compound and some by larger motors and corresponding controllers.

Experiments were made on one blooming mill table not because it was actively causing trouble but to try to improve conditions. In this case three different gear ratios were tried out from motors to table rollers. Graphic current curves were taken and the operation of each arrangement was analyzed for rate of acceleration of motors in r.p.m.,of table in feet per minute and ultimate speed of table in feet per minute and in the power demand on the motor with different ratios. The ratio best suited to the application was installed.

These are only a few examples of what can be done by intelligent investigation. Satisfactory operation in the mill can be obtained only by studying the demands of the application and using the equipment which the investigation shows is needed.

A careful and systematic analysis of all motor failures together with a study of the operating cycle by means of graphic instruments whenever motor or controller operation seems faulty, will materially reduce the maintenance cost of the electrical equipment in many cases, and will minimize the operating delays due to such causes.

The Engineering Evolution of Electrical Apparatus-XXXII

The History of Indicating Meters

CHAS. R. RIKER

SYNCHROSCOPES

During the early operation of the alternating-current system it was the general impression that alternating-current generators could not be operated in parallel and for years the individual generators were connected to separate circuits. When the possibility of parallel operation was demonstrated, synchronizing was done by means of lamps, but as the generators became larger, the requirements of a more sensitive means of indicating the exact time of synchronism became apparent. The first instrument of this type, it is believed, was that provided for the Niagara Falls installation, which consisted simply of a differential induction voltmeter connected across the paralleling switch, whose needle was swung away from the zero position when the voltages of the two generators were not exactly in opposition. The instant of synchronism was indicated by the needle returning to the zero position, which it did periodically.

Another synchronizing device which was used to a certain extent was known as a growler. This instrument consisted of a metal diaphragm which vibrated after the fashion of the diaphragm in a telephone receiver, being caused to vibrate by a differential magnet, one of the coils of which was connected across the bus-bars, and the other across the incoming machine. The vibration of the diaphragm was proportional to the difference between phase angles between the incoming machine and the bus-bars, the noise being loudest when the machines were entirely out of phase, and being silent when the machines were exactly in phase. This apparatus had the same disadvantages that synchronizing with lights does, in that the exact instant of synchronism was not very clearly defined and also it did not indicate whether the incoming machine was fast or slow.

The type of synchroscope shown in Fig. 30 was a great improvement over previous methods of syn-

chronizing in that it indicated the exact instant of synchronism and also indicated whether the incoming machine was running fast or slow. The principle of operation of this instrument, which was known as the inductor type, is shown in Fig. 31, in which coils *M, N* and *C* were stationary and the moving system consisted of an iron armature mounted on a shaft to which the pointer was attached. A rotating torque was produced whose frequency was equal to the difference between the frequencies of the machine connected to the synchroscope.

A variation of this type was developed by Mr. P. M. Lincoln. As shown in Fig. 32, this instrument acts as an induction motor, the moving element rotating at a speed which is equal to the difference in frequencies of the machine to be synchronized. For use in large stations where it was necessary that the instrument be visible from a distance, this instrument was made with a 36 inch dial similar to that shown in Fig. 33, a tubular incandescent lamp being attached to the pointer and the letters *F, S* and the synchronous position being lighted by internal lamps. A still further development of the synchroscope is the automatic synchronizer shown in Fig. 34, which automatically establishes the circuits which close the switch of the incoming machine at the instant of synchronism, provided the difference in speeds is within a certain predetermined minimum.

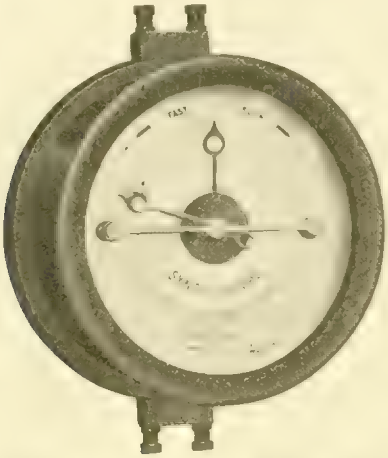


FIG. 30—INDUCTOR TYPE SYNCHROSCOPE

POWER-FACTOR METERS

Until the commercialism of the induction motor, little attention was paid to the power-factor and frequency of alternating-current circuits, as their power-factor was always fairly good and the exact frequency made very little difference. However, after the growing induction motor loads began to decrease the power-factors of the circuits and the synchronous motor and rotary converter became available for power-factor correction, power-factor meters were constructed along the same lines as the other types of switchboard instruments. Two types of power-factor meters have been in general use. In one, which is built upon the moving coil principle, as shown in Fig. 35, the moving element has two voltage coils fixed at right angles to each other and the stationary coils are parallel to the axis of the two moving coils. The currents in the voltage coils differ from each other in phase and depend on the phase relations of the voltage and current of the circuit for their phase relation to the current in the stationary coils.

Another type of power-factor meter shown in Fig. 36 is built on the magnetic vane principle. A rotating field is produced in the coils *M, N* and *R* of the three-phase meter by connecting them in series with different phases. The movable iron vane to which the pointer is attached, is excited with single-phase flux from the coil *C* whose current is in phase with the voltage of one phase of the circuit. As the iron vane will be attracted or repelled by the fields of the coils *M, N* and *R*, it takes up a position where the zero of the rotating field occurs at the same instant as the zero of its own field thus indicating the angle of phase difference. In this form of meter no connection is required between the fixed and moving elements and as there are no moving coils there are no delicate flexible connecting leads. Hence the pointer is capable of continuous rotation and can therefore indicate any angle of lag or lead with forward or reversed power.

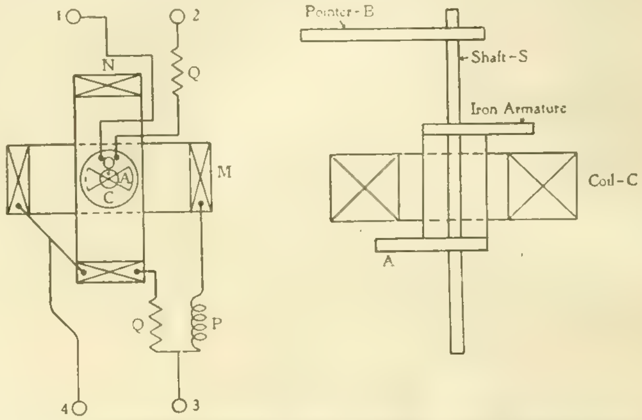


FIG. 31 SCHEMATIC DIAGRAM OF INDUCTOR TYPE SYNCHROSCOPE

Any power-factor meter by changing the scale can be converted to a reactive factor meter indicating the sine of the angle of lag or lead rather than the cosine.

It is interesting to note that these instruments indicate the angle of lag or lead rather than the true power-factor of the circuit and that there is no meter in common use which indicates true power-factor. However, the difference is usually negligible except on circuits having a very distorted wave shape, or on unbalanced polyphase circuits.

FREQUENCY METERS

Early frequency indications were obtained by noting the speed of a generator either by means of a speed counter or by the indication of a millivoltmeter connected to a magneto-generator which in turn was belted or geared to the alternator shaft. One of the earliest commercially successful frequency meters was introduced by Hartman and Braun, and is based on the principle of resonance. A group of steel stripes having successively higher natural periods of vibration are fastened to a base and subjected to a series of magnetic pulls whose frequency is equal to that of the circuit to

be measured, when that reed whose natural frequency corresponds closely to that of the circuit will respond. A modern meter of this type is shown in Fig. 37.

Another type of frequency meter operates on the same principle as the magnetic vane type of ammeter and voltmeter. Two coils set at right angles to one another are excited by current having a 90 degree phase relation produced by the split-phase principle. The direction of the resultant field is determined by the ratio of the currents in the coils, which is in turn dependent on the frequency. The needle which is attached to the magnetic vane then indicates the direction of this magnetic field. Still another type which is dependent on the induction principle, is shown in Fig. 38. It consists of two induction voltmeter elements, tending to move a disc in opposite directions. One of the elements of the disc is in series with a resistor and the other with a reactor, so that any change in the frequency changes the relative strengths of the two elements and causes rotation. With a perfectly round disc this rotation would be continuous, but the shape of the disc is such that rotation changes the area of the disc under the elements, which produces a stable condition. This special construction of the disc obviates any necessity for control springs.

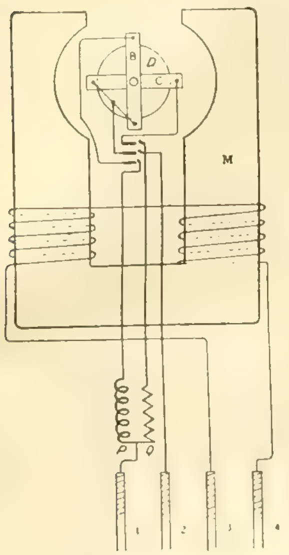


FIG. 32—SCHEMATIC DIAGRAM OF MOTOR TYPE SYNCHROSCOPE

FIG. 33—MOTOR TYPE SYNCHROSCOPE WITH ILLUMINATED POINTER

GROUND DETECTORS

With the earlier circuits a ground detector consisted simply of two lamps connected in series across the line with the connection between them grounded. Normally each lamp burned at half brilliancy, but a ground on one line caused the lamp connected to that line to go out while the other burned at full brightness. Where the voltage was too high for two lamps or for a group of lamps in series, a small transformer was supplied. However, with the higher voltages now common in generating stations the electrostatic ground detector shown in Figs. 39 and 40 became more generally useful. The single-phase detector consists of two stationary vanes which were connected through condensers to the lines, and a movable vane which is connected to ground. A ground on one line causes the needle to swing away from the vane connected to that line. Similarly the three-phase detector has three stationary vanes, connected through condensers to the three lines and a central movable grounded vane which moves away from the fixed vane connected to a grounded line.

GENERAL METER CHARACTERISTICS.

Practically all of the types of instruments heretofore described, except those depending upon gravity for their operation have been manufactured in both portable and switchboard forms. The portable forms were, of course, made smaller, their principle characteristics being ruggedness rather than extreme accuracy. The portable instruments were also designed for a maximum of serviceability and hence the voltmeters were usually provided with double scales giving two maximum scale readings, and were also frequently provided with multipliers or resistors which could be connected in series with them for use on high voltages. Similarly direct-current ammeters were provided with shunts of various sizes to give a wide range of usefulness and alternating-current ammeters were similarly provided with curent transformers. The most generally useful instruments for portable service have been of the D'Arsonval type for direct-current instruments and the dynamometer, magnetic vane and induction types for alternating current.

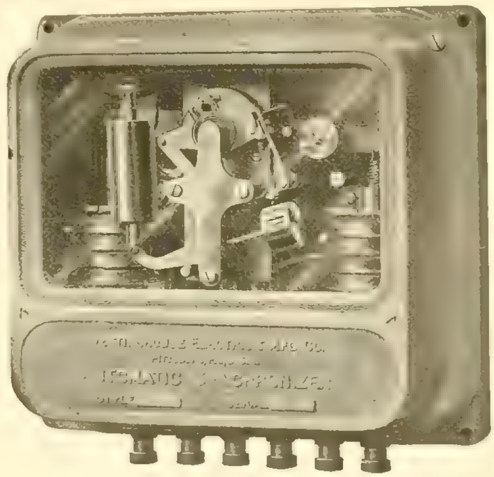


FIG. 34—AUTOMATIC SYNCHRONIZER

Laboratory Instruments—In instruments of this type, extreme accuracy is an essential but semi-portability is also desirable. For many years the Weston semi-portable laboratory standard was the only instrument of this kind available, and this instrument formed a standard against which portable instruments were checked in many central stations and universities. As there was, at that time, no satisfactory alternating-current standard meter, alternating-current portable and switchboard instruments were calibrated on direct current. This meter was of the D'Arsonval type, of the same general construction as of the Weston portable instruments, but having larger permanent magnets and more sensitive moving elements, and a longer pointer and scale, the scale being arranged with five circular lines and a triangular cross line between each division, producing a vernier effect. Although not dependent on

the action of gravity it was provided with a spirit level and always used in exactly a horizontal position. Other similar laboratory instruments of the D'Arsonval type were subsequently brought out by other manufacturers.

To meet the demand for alternating-current precision instruments the Kelvin current balance was sold in this country to some extent, but its use commercially was practically eliminated by the introduction of the Westinghouse precision instruments of this same general type previously described and illustrated in Figs. 15 and 16 (July '18).

Switchboard Instruments—The main requirements of the switchboard indicating meter are somewhat different from those of portable instruments. Weight is usually a secondary consideration, but they require a large scale to provide legibility at a distance and they must also be compact so as not to require too much space on the switchboard. The requirements of legibility led to the large illuminated dial instruments such as that shown in Fig. 41. These instruments are operated on the principles previously described, usually D'Arsonval for direct current and dynamometer or magnetic vane for alternating current, simply being made larger with a longer pointer and with a ground glass scale which could be lighted from the rear. An adjustable pointer was usually provided on voltmeters to indicate the normal position to the indicating needle.

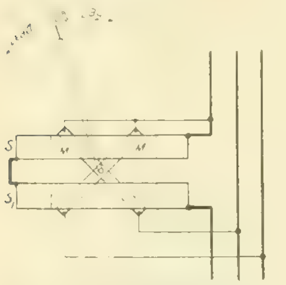


FIG. 35—DYNAMOMETER OR MOVING COIL TYPE POWER-FACTOR METER

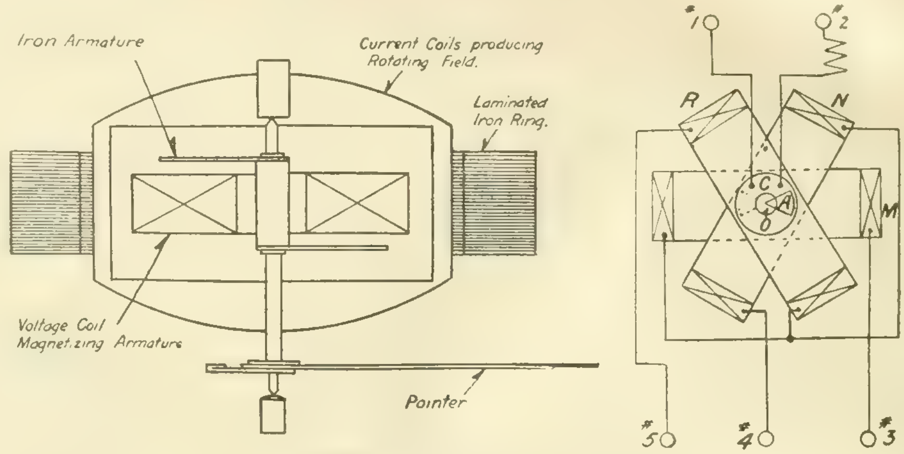


FIG. 36—MOVING IRON TYPE POWER-FACTOR METER

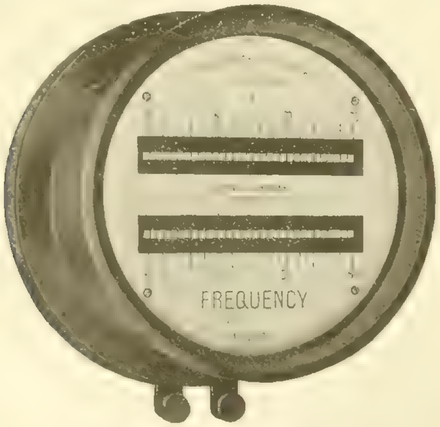


FIG. 37—FREQUENCY METER OF THE VIBRATION TYPE

Where space requirements were more rigid the long scale of the round induction instruments proved very advantageous. Where the space requirements were still more rigid as for instance, in the distributing panels of many large stations the horizontal edgewise instruments shown in Fig. 42 and especially the vertical edgewise meters shown in Fig. 43 were especially satisfactory. These latter meters were of the D'Arsonal type for direct current and usually of the induction type for alternating current, their principal usefulness occuring in 500 volt street railway switchboard and 110-220 volt Edison stations and substations in a few of the larger cities. The inherent disadvantages of the vertical or horizontal scale and the type of pointer which is necessitated thereby have, however, caused these latter meters to be superseded in many cases by the smaller sizes of the round type meters.

So far as general usefulness for either switchboard or portable work is concerned, practically any of the types described will operate satisfactorily, the difference between two different instruments depending more upon care in design and delicacy and accuracy in workmanship than upon the principle of operation. D'Arsonval instruments are of course limited to direct-current and induction meters to alternating-current. Static instruments are little used and hot wire instruments are commercially limited to high frequency circuits. A comparison of the principal characteristics of the different types is given in Table I.

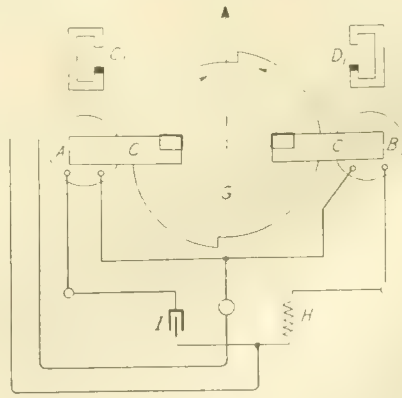


FIG. 38—INDUCTION TYPE FREQUENCY METER

Mounting of Moving Parts—Freedom from friction is an essential in any indicating instrument. In the earliest instruments the moving elements were supported by a torsion thread as in the galvanometers or

on a single point steel pivot as in the compasses used with the earlier sine and tangent galvanometers. The early Siemans dynamometers were also supported in this way, and hence require to be carefully leveled before using. In those switchboard instruments which depended upon gravity for their operation a pair of knife edges forms a reliable and practically frictionless support. The requirements of portability, however, soon

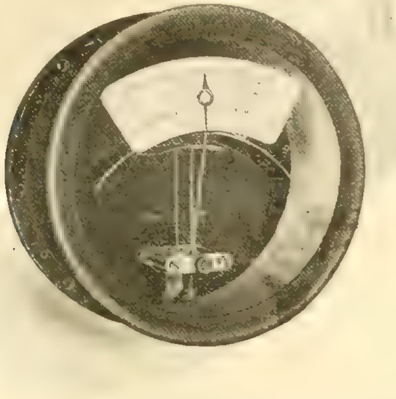


FIG. 39—SINGLE-PHASE STATIC GROUND DETECTOR

lead to pivoting the shaft of the moving element at both ends as the balance wheel of a watch is pivoted, and in practically all of the finer instruments, jewel pivot cups are provided.

At the same time the elimination of friction allows a sudden impulse to swing the needle far beyond its true position and permits it to oscillate for some time before coming to rest, so that with fluctuating loads it was almost impossible to obtain a reading. One of the great advantages of the early D'Arsonval instruments was their dead beat characteristic, produced by the fact that the moving element rotated in a stationary magnetic field. Such a method of damping is practically impossible with the moving iron or dynamometer instruments and dampers were provided for these instruments in the form of light fans attached to the pointer. The

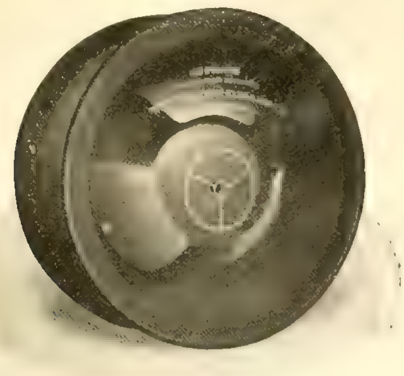


FIG. 40—POLYPHASE STATIC GROUND DETECTOR

great disadvantage of this fan was the greatly increased weight added to the moving element which tended to increase the friction and decrease the sensibility of the instruments; nor was it as effective as the magnetic action in the D'Arsonval instrument. To obviate the need of such a fan, various forms of friction devices were used, consisting usually of a light wire rubbing against the pointer, or a damper rubbing against a light metal disc mounted on the spindle. The friction device was released from contact by a button on the outside of the case, in some types when the button was pressed, and in others when it was released. Some meters were equipped with both a fan and a friction device. Other

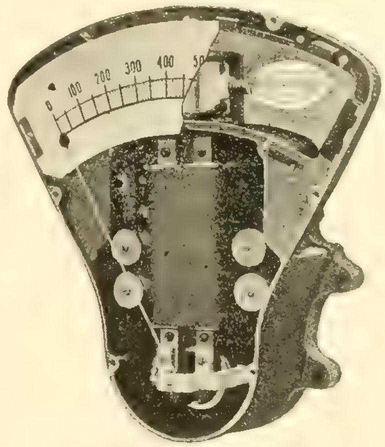


FIG. 41—THOMSON ASTATIC ILLUMINATED DIAL VOLTMETER

So far as classification is concerned, this instrument is a hybrid. It may be considered as a double D'Arsonval type instrument, in which the permanent magnets are replaced by separately-excited soft iron cores, the retarding springs are replaced by iron control pieces located in leakage gaps of the same electromagnets, and the shape and arrangement of the pole pieces and the moving coils are such that it is independent of the influence of stray fields—whence the name. The ratio of torque to weight of moving element is high, and is not affected by ordinary fluctuations in the exciting circuit. It can be used only on direct-current.

meters, especially of the magnetic vane type, in which the moving element is light, were not damped, but relied upon a spring at each end of the scale to absorb the shock of a sudden impulse without bending the needle. It is unfortunate that damping is most difficult to accomplish on the alternating current instruments where it is most needed, because the torque is proportional to the square of the current. Hence, one of the great advantages of the induction type alternating current instruments is the dead beat characteristic which can be

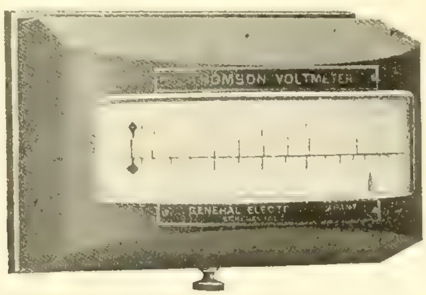


FIG. 42—THOMSON INCLINED COIL HORIZONTAL EDGEWISE AMMETER

produced by some form of magnetic damping, which strongly opposes any large, sudden movement, but offers no opposition to slight or slow movements.

COMPENSATED INSTRUMENTS

The principle of compensation,—that is adjusting a meter so that its reading will be corrected automatically for certain conditions, was early recognized. One of

the earliest uses of this principle was in making a central station voltmeter read the voltage at the center of distribution by bucking the voltmeter coil by another coil excited by the drop over a resistance in series with the line, or by the current in the secondary of a series transformer. Such devices were in use as early as 1888. As circuits became longer and more complicated, compensators were designed which could be adjusted independently for ohmic and reactance drop. This form of compensation is still in use for central station voltmeters and for automatic voltage regulators.

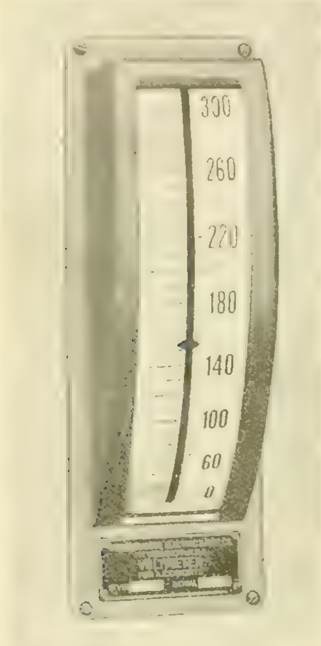


FIG. 43. WESTINGHOUSE INDUCTION TYPE VERTICAL DIAL AMMETER

TABLE I—GENERAL CHARACTERISTICS OF METER TYPES

Meter Characteristics		Static	Hot Wire	D'Arsonval	Dynamometer	Kelvin Balance	Moving Iron	Induction
Accuracy		Fair	Fair	High	High	High	Good	Good
D. C. or A. C.		Both	Both	D. C.	Both	Both	Both	A. C.
Frequency and Wave Form		No	No (2)		No	No	Slight	Slight
Stray Magnetic Fields		No	No.	Slight	Only when of same frequency	No.	Yes	Slight and only when of same frequency
External Static Fields		Yes	No	Slight	Yes	No	Yes	Slight
Temperature (1)		No	Slight	Slight	Slight	Slight	Slight	Slight
Scale	Reading	A	With Square	Direct proportion	A	With [illegible]	A	A
	Angular Deflection	Short	Geared for any length	Medium	Short (3)	None (4)	Short	Long
Ratio Torque to Weight		Low	High	High	Low	Low	Low	High

A—Normally the deflection is proportional to the square of the current or voltage and directly proportional to the watts; but this can be modified by changing the shape and position of the moving element.

(1)—In general, ammeters are free from temperature errors, except as temperature affects the permeability of the iron, while voltmeters and wattmeters are subject to such errors, but in this connection a shunted ammeter must be considered as a mil-voltmeter, and subject to such errors.

(2)—Skin effect may introduce errors in heavy current, high frequency meters.

(3)—Zero reading dynamometer instruments have a long scale—nearly 360°.

(4)—Kelvin balance type precision instruments have a zero reading scale, with long scale range.

A somewhat different form of compensation was used to correct wattmeters for their own losses. It is impossible to connect a wattmeter so it will not measure the loss in one of its coils. But as the loss in the shunt coil is constant at any voltage, it is possible to compensate for this loss by winding a few turns in the opposite direction around the shunt coils, these turns being in some instruments connected to the binding posts in such a manner that they could be connected into or omitted from the circuit at discretion. This is of importance only in low range instruments.

Still another form of compensation is exemplified by the "iron-loss voltmeter" which is adjusted to read not the actual voltage of the circuit to which it is connected, but the sine wave voltage of normal frequency which is equivalent to the actual voltage, frequency and wave shape of the circuit to which it is connected. It is useful in testing iron loss of transformers or other apparatus which are guaranteed on a sine wave basis, but which, by reason of local conditions, must be tested under somewhat abnormal conditions.

CONCLUSION

To appreciate fully, at how early a date the principles of electrical measurement were understood, one must remember that electrical experiments have been performed for over a century with the aid of powerful batteries, whereas the commercial use of electricity covers less than 50 years. The retarding effect, produced on a moving conductor in a strong magnetic field, was utilized in some of the earliest electrostatic meters and solenoid instruments, in which the permanent magnets were introduced solely to reduce oscillations of the needle, as well as in the D'Arsonval instruments, where the damping effect was more incidental. Similarly the use of a very light magnetic circuit on solenoid or magnetic vane instruments, which would become saturated on low magnetizations and thus tend to produce a proportional scale where normally the pointer deflection would vary with the square of the current, was taken advantage of in some of the earliest instruments. In fact the importance of a uniform scale was over-emphasized in many of the earlier instruments, involving a sacrifice in accuracy. Knife edge pointers swinging over a mirror to avoid parallax errors have been in use for at least 35 years; and with the single exception of induction-type meters, no fundamentally new principles of meter design have been developed during this same period of time.

Contrary to almost all other electrical equipment, instrument development has not been furthered by the tremendously rapid growth in the size of modern central stations. The growth of a station from 10 000 to 100 000 kw has meant big problems for the generator designer, and for the circuit breaker engineer. The instrument builder has merely enlarged the cross-section of his shunts or increased the number of primary turns on the current transformers feeding the ammeters and wattmeters. The voltmeter, the frequency meter, and the synchroscope, are the same in the larger station as in the smaller one. Nor would there seem to be any reason apparent why these same instruments will not be entirely adequate for some time to come.

The Behavior of Alternators with Zero Power-Factor Leading Current

F. D. Newbury

When leading current flows in an alternator armature, the effect of the armature reactance and reaction is to reduce the field current that is necessary to maintain constant voltage.* If the leading current has a sufficiently high value, its magnetizing effect may become great enough to make the alternator self-exciting; that is, it will generate normal voltage without any field excitation; and, if the armature current is increased beyond this value, the voltage can be held down to normal only by reversing the direction of the field current. In Fig. 9 (p. 256 July), showing the voltage and flux conditions at zero power-factor with rated leading current, it is seen that the field current has been reduced to 20 percent of its no-load value by the magnetizing effect of field load current. In this particular case, it would require only a small increase

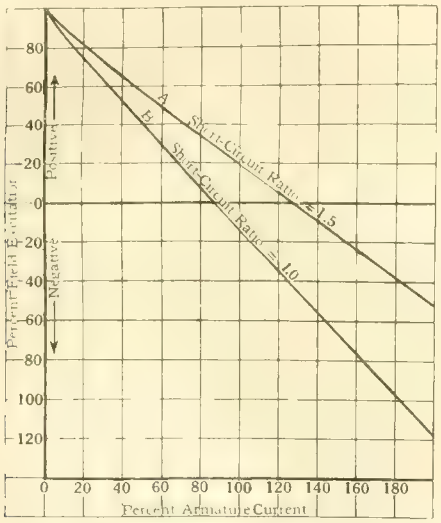


FIG. 1 EXCITATION CHARACTERISTICS OF TYPICAL ALTERNATORS
With zero power-factor leading current.

in leading current to further reduce the field current to zero.

Saturation plays a much less important part when the condition of leading current exists than with lagging current. With lagging current, an induced voltage higher than the terminal voltage must be generated and this involves high magnetic densities and increased ampere-turns. With leading currents, an induced voltage lower than the terminal voltage is generated so that in this case saturation affects the results only near zero armature current and then only to the extent that the no-load saturation curve below normal voltage departs from a straight line. This latter statement is true only when it is assumed that the voltage is constant at its normal value. Under the condition of self-excitation, discussed later, when the terminal voltage increases until stopped by saturation, higher terminal voltages are involved and a greater degree of saturation exists, but still to a considerably less degree than with lagging currents, and the same terminal voltage.

TABLE I—PERCENT GENERATOR EXCITATION WITH ZERO POWER-FACTOR LEADING CURRENT

Short-circuit ratio = 1.5

Armature Current	Terminal Volts	Reactance Volts	Induced Volts	Resultant Amp-turns	Equivalent Armature Amp-turns	Field Amp-turns
0	100	0	100	100	0	+100
50	100	10	90	83	25	+ 58
100	100	20	80	71	50	+ 21
125	100	25	75	65	62	+ 3
150	100	30	70	60	75	— 15
200	100	40	60	50	100	— 50

The values of excitation corresponding to various armature currents may be determined quite simply since, neglecting the small armature resistance voltage, the arithmetical difference between the terminal voltage and the reactance voltage is the induced voltage and the difference between the ampere-turns corresponding to this induced voltage and the armature reaction (in equivalent field ampere-turns) is the field ampere-turns. Excitations for various load currents for the particular generator previously used as an example (Fig. 10, July) are given in Table I. These figures are based on 20 percent reactance voltage and armature reaction equivalent to 50 percent of no-load normal voltage field ampere-turns. With the saturation curve of Fig. 10 (July), these figures result in a short-circuit ratio of 1.5. If it be assumed that with the same armature winding, but with a smaller air-gap, the alternator still has 20 percent reactance, but the armature reaction is equivalent to 83 percent of the reduced no-load field-ampere-turns, the new short-circuit ratio (again referring to Fig. 10) is 1.00. For this generator, the excitations required for different leading armature currents are shown in Table II.

TABLE II—PERCENT GENERATOR EXCITATION WITH ZERO POWER-FACTOR LEADING CURRENT

Short-circuit ratio = 1.0

Armature Current	Terminal Volts	Reactance Volts	Induced Volts	Resultant Amp-turns	Armature Amp-turns	Field Amp-turns
0	100	0	100	100	0	+100
50	100	10	90	83	41	+ 42
100	100	20	80	70	83	— 13
125	100	25	75	65	104	— 39
150	100	30	70	60	125	— 65
200	100	40	60	48	167	—119

*This article should be read as a continuation of the author's contribution on "Variation of Alternator Excitation with Load" in the July '18 issue of the Journal. See also the article on "Characteristics of Alternators when Excited by Armature Currents" by F. T. Hague in the Journal for Aug., '15, p. 368.

The data of Tables I and II are plotted in Fig. 1. Near zero armature current the curve bends slightly on account of the bend in the no-load saturation curve near normal voltage. With more than half load current, the relation between armature current and excitation is a straight line. If the small effect of saturation were neglected, these excitation curves would cross the line of zero field excitation at the current equal to normal current times the short-circuit ratio. For example, with a short-circuit ratio of unity, the magnetizing effect of the armature would equal the no-load normal voltage field excitation at rated armature current. On account of saturation, this equality exists at a somewhat lower armature current.

Thus far, it has been assumed that the condenser load, originating the leading current, has been variable, and that the alternator excitation has been under control, in direction as well as in magnitude, so that a constant terminal voltage could be maintained. These conditions might exist in the case of an alternator connected to a transmission line having a large synchronous condenser at the receiver end. Another practical set of circumstances that sometimes deserves attention occurs when an alternator is connected to an unloaded transmission line. If the admittance of the line as a condenser is high and the magnetizing effect of the armature current is also high, that is, if the alternator short-circuit ratio is low, the alternator may become self-exciting and generate an objectionably high voltage before a stable voltage is reached. It is assumed that the exciting current cannot be reversed and so control the voltage. It requires a transmission line of considerable length operated at a voltage higher than 100 000 volts, before self-exciting conditions will be encountered. A rough idea of the conditions under which this action may take place is given by the following example.* A transmission line, designed to transmit 50 000 kw at 90 percent power-factor, 140 000 volts, 60 cycles, for 120 miles, has a total charging current of 52.5 amperes per phase. This is roughly one-quarter of the rated line current. If the generating units were 12 000 k.v.a., or less, in capacity, one alternator connected to the line would probably be self-exciting, and would generate normal voltage or higher. It is assumed that the generator short-circuit ratio is in the neighborhood of unity. If this ratio is higher, a smaller unit could be safely connected to the unloaded line.

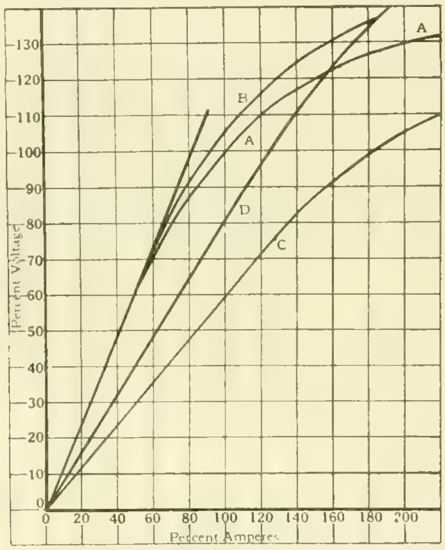


FIG. 2—SATURATION CURVES OF TYPICAL ALTERNATORS

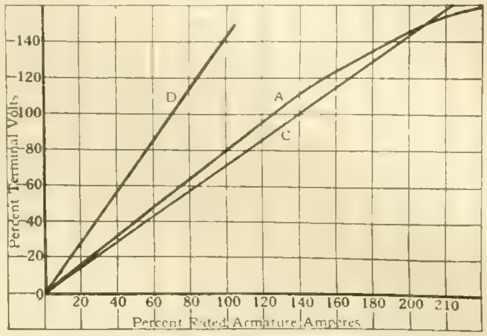


FIG. 3—SATURATION CONDITIONS REQUIRED FOR STABLE SELF-EXCITATION

An alternator when excited by leading current in its armature winding has voltage characteristics quite similar to a direct-current series generator. In both, any increase in armature current results in a proportional increase in excitation; the generator will be self-exciting only when the load circuit has a sufficiently high admittance; and, when self-exciting, the generator will increase its terminal voltage and current until the load current requires as large a terminal voltage (because of line drop) as it will produce by its magnetizing action in the alternator. In addition, the alternator armature current generates a voltage in the winding, by reactance, that adds to the voltage induced by the armature reaction flux.

Under conditions of self-excitation, the saturation curve of the alternator is considerably straighter than when the same terminal voltage is produced by field excitation without load. An appreciable part of the terminal voltage, in the former case, is produced by armature reactance that does not require any flux in the major part of the magnetic circuit; also, the flux in the field structure is further reduced by the absence of flux leakage from pole to pole that exists when the flux is produced by ampere-turns on the field poles. These matters will be made clear by reference to Fig. 2. Curve *A* is the ordinary no-load saturation curve of the alternator previously shown in Fig. 10 (July); curve *B* is this saturation curve modified by the omission of the ampere-turns required by pole leakage; curve *C* is the

TABLE III—PERCENT GENERATOR EXCITATION

Armature Amperes	Magnetizing Effect of Arm. Amps (expressed in Fld. Amps)	Induced Volts (from Curve *B* and Col. 2	Reactance Volts	Terminal Volts
50	25	30	10	40
100	50	60	20	80
150	75	87	30	117
200	100	105	40	145

*The transmission line calculations are given in Section 11, paragraph 24, Fourth Edition of the *Standard Handbook.*

same as curve *B*, except that the exciting ampere-turns (on the horizontal scale) are expressed in armature amperes instead of in field amperes; and curve *D* is curve *C* with the addition of the reactance volts. The method of obtaining curves *C* and *D* is evident from Table III. The importance of the shape of the saturation curve lies in the fact that it is saturation that limits the generated voltage. With any value of line capacity sufficiently high to produce self-excitation, the voltage and current would increase indefinitely were it not for saturation. The condition for stable terminal voltage, in either the series direct-current or self-excited alternating-current generator, is equality between the line terminal voltage required to circulate a given current and the generator voltage produced by that same current. In Fig. 3 curve *OA* is the saturation curve *D* of Fig. 2. The straight line *OC* gives corresponding values of line current and terminal voltage for an assumed transmission line such that the line charging current at rated voltage is 140 percent of the generator rating. This would be equivalent to connecting a 6000 k.v.a. generator to the 50 000 kw line previously cited. At any current value, these two curves show the available voltage for circulating current (curve *OA*) and the required voltage (curve *OC*). Where they cross (at 208 percent rated amperes and 148 percent rated voltage) these voltages just balance and this is the point of stable current and voltage. Obviously, it would be unsafe, both from the standpoints of generator heating and from maximum line voltage to connect a generator of this size to this particular line. If two such generators were connected to the line, the curve *OC* would be replaced by curve *OD*, which shows that the generators would not be self-exciting as at no current value is the generated voltage sufficient to circulate the current. In these circumstances field excitation would be necessary.

Whether a generator will be self-exciting depends on:—

a—The total charging current of the line.

b—The relation between the line charging current and rated generator current.

c—The armature reaction, reactance and shape of the saturation curve of the generator.

The Essentials of Transformer Practice—XIV

Reactors

E. G. Reed

A REACTANCE coil or reactor is composed of one or more turns of a conductor linking with a magnetic circuit, which may be air or metal. When a voltage is impressed on such a coil, a current flows which may be thought of as the magnetizing current of its magnetic circuit. An ideal reactance coil would be one in which the current flowing with a given impressed voltage would be 90 degrees behind the voltage in time-phase relation. Since there is a voltage drop in the conductor which is in phase with the current, such a condition cannot exist, and a reactance coil is in reality an impedance coil with the reactance element predominating.

The rating of a reactance or impedance coil at a given frequency might be given in ohms, but as such a rating gives no clue to its current-carrying capacity it is usually given in k.v.a. The rating is the product of the voltage, expressed in kilovolts, required to force a given current through the coil and the value of the current in amperes.

The reactance of a coil with an air magnetic circuit is small, so that a large current is established by a small impressed voltage. The reactance is small because the reluctance of the magnetic circuit is large and a large current is required to establish a given flux density and thus produce a given counter electromotive force. Therefore, in order to produce any considerable counter electromotive force, a relatively large number of turns or a large area of the magnetic circuit is required. On the other hand with an iron magnetic circuit a large voltage is required to send a small current through the coil. By putting a gap in the iron circuit, its reluctance is increased so that the ampere-turns required to establish a given magnetic density are also increased. Any desired step between a circuit of air and one of iron may be secured by placing air-gaps in the circuit. There are therefore three types of reactance coils as follows:—

1—With a magnetic circuit of air.
2—With a magnetic circuit of iron.
3—With a magnetic circuit of iron having air-gaps.

One of the main problems in designing air reactors is to keep the eddy-current loss in the conductor to a reasonably low value. The problem in this respect is similar to that described in part II under Copper Loss.*

WITH A MAGNETIC CIRCUIT OF AIR

The voltage drop across a reactance coil without iron is proportional to the current flowing, because air, which has a constant permeability, forms the magnetic circuit. For applications where the voltage is required to vary directly with the current flowing, up to such a value as will heat the copper to the permissible limit in a relatively short time, the air reactor is preferable. Air reactors have a number of applications, among them being:—

1—Standards for precise measurements.
2—Coils for reactance circuit-breakers.
3—To counterbalance the effect of distributed capacity in transmission lines.
4—In transmission lines, to protect against lightning disturbances.
5—To protect generator and feeder circuits against short-circuits.

*In the Journal for August 1917, p. 308.

As far as the calculation is concerned the simplest form of a reactor is that of a long solenoid shown in Fig. 1. For such a coil the inductance, in abhenrys is:—

$$L = \frac{4\pi^2\, a^2\, T^2}{l}$$

where a is the mean radius of the coil, l its length in centimeters and T its number of turns. When L is expressed in henrys and the dimensions in inches, this equation becomes:—

$$L = \frac{1.00\, a^2}{10^7} \frac{T^2}{l} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

While there is a considerable error in this formula due to the end effect, the variations in L due to changes in l are almost exactly proportional to the change in l. Therefore it may be used without error for calculating variations of L due to changes in l. The counter e.m.f. of this coil is $2\pi\, fLI$, where f is the frequency and I the current flowing in amperes. Therefore by the use of equation (1):—

$$E = \frac{2\pi}{10^7} \times \frac{f\, a^2\, T^2\, I}{l} = \frac{6.28}{10^7} \times \frac{f\, a^2\, T^2\, I}{l} \quad \ldots\ldots \quad (2)$$

Example—What is the voltage and k.v.a. rating of a reactor which has the following constants? $f = 60$; $a = 8.82$; $T = 400$; $I = 53$; $l = 50$.

From equation (2):—

$$E = \frac{6.28}{10^7} \times \frac{60 \times 8.82^2 \times 400^2 \times 53}{50} = 496 \text{ volts.}$$

With a current of 53 amperes the rating is $\frac{496 \times 53}{1000}$ or 26.2 k.v.a.

The simple form of solenoid reactor shown in Fig. 1 does not give a maximum reactance value for a given

FIG. 1—REACTOR IN THE FORM OF A LONG SOLENOID

amount of material and therefore practical reactors, particularly of the feeder circuit protective type which are usually of fairly large size, are not built in this form and their calculation is therefore more involved.*

The form of circular reactor shown in Fig. 2, where a section through the coil is a square, approaches more closely to the most economical proportions. It has further been found that for a coil of this form, in order to obtain a maximum inductance for a given weight of conductor, the ratio $a \div b$ should be equal to 1.47. Substituting this relation in Weinstein's formulæ given in the Bulletin,* which is applicable to a coil of square cross-section, gives:—

$$L = \frac{a\, T^2}{238 \times 10^5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where L is expressed in henrys and a in inches.

Since the counter e.m.f. of the coil is $2\pi\, fLI$, from equation (3):—

$$E = \frac{f\, a\, I\, T^2}{38 \times 10^5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Example—What is the counter e.m.f. of the coil given in the preceeding example when operating on a 60 cycle circuit and with a current of 53 amperes flowing?

*The Bulletin of the Bureau of Standards, Vol. 8, No. 1, gives a very extensive collection of formulae for the calculation of reactance coils of all proportions.

From equation (4):—

$$E = \frac{60 \times 8.82 \times 53 \times 400^2}{38 \times 10^5} = 1180$$

If 1180 volts will force approximately 53 amperes through this coil its capacity rating will be $\frac{1180 \times 53}{1000}$ or 63 k.v.a.

If practical considerations, as for example heating or floor space requirements for current limiting reactors, require a departure from the coil of square cross-section, a different formula must be used.

WITH A MAGNETIC CIRCUIT OF IRON

Reactors with a magnetic circuit of iron have a very limited field of application. Shunt coils for the individual lamps of a series incandescent lighting circuit form one special application of this class. For this case instead of starting from a formula for the inductance, it is preferable to start from the fundamental equation of the transformer, since the reluctance of the iron as compared to the air magnetic circuit is much easier to calculate. At a given voltage E and frequency f the coil must have its number of turns T the square inches A_1 of the cross-section of the magnetic circuit, and the magnetic flux density in gausses B so related as to satisfy this fundamental equation. For this case, equation (5) in Part IV* becomes:—

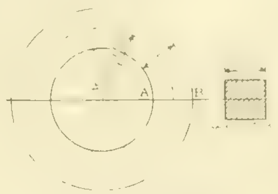


FIG. 2—REACTOR WITH A MAGNETIC CIRCUIT OF AIR
Feeder circuit protective type.

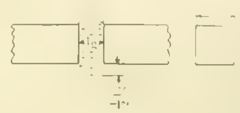


FIG. 3—SECTION OF A MAGNETIC CIRCUIT
Showing the fringing of the magnetic flux at an air-gap in an iron circuit.

$$E = \frac{f}{3.5 \times 10^6}\, T\, A_1\, B \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Example—What is the counter electromotive-force of a reactor with an iron magnetic circuit, which has the following constants? $f = 60$; $T = 250$; $A_1 = 1.5$; $B = 17100$.

From equation (5):—

$$E = \frac{60}{3.5 \times 10^6} \times 250 \times 1.5 \times 17100 = 110 \text{ Volts}$$

The current which this voltage will force through the coil when impressed on its terminals, depends on the reluctance of its magnetic circuit. The value of this current may be calculated from the permeability of the material, but the most practical method is to calculate it from a curve similar to that in Part III, Fig. 5.**

Example—What current will 110 volts force through the reactance coil given in the preceeding example which has 4.9 pounds of iron in its magnetic circuit, if the magnetic induction is 17100 gausses?

From a curve similar to that in Fig. 5, Part III, but which gives a greater range of values, the apparent watts is taken as 90 watts per pound. The total apparent loss is 90 × 4.9 or 440 watts and the current supplying this loss will be $\frac{440}{110}$ or 4 amperes. If approximately 110 volts is required to force 4

*In the JOURNAL for Nov. 1917, p. 476.

**In the JOURNAL for Sept. 1917, p. 359.

amperes through a reactance coil, its rating will be $\frac{110 \times 4}{1000}$ or 0.44 k.v.a.

Any change which affects the reluctance of the circuit will change the current which will pass through the coil. For example, slight gaps between the punchings where they butt together will change this reluctance. If the voltage impressed on the coil changes, the permeability of the iron changes. Therefore the current flowing through the coil will not be proportional to the voltage impressed on its terminals. However the current increases approximately as the voltage up to the point where the iron begins to be saturated, after which point the current will increase faster than the voltage.

It is practical to build reactors with a closed iron magnetic circuit only for small current ratings, due to the low reluctance of such a circuit, and consequently the practical application of these coils is very limited. When any considerable current capacity is required it is necessary to increase the reluctance of the magnetic circuit by introducing air-gaps.

WITH A MAGNETIC CIRCUIT OF IRON HAVING AIR-GAPS

In this case the relation between the impressed voltage, frequency, number of turns, area of magnetic circuit and induction is the same as that given in equation (5). Also the current which will flow through the coil with a given impressed voltage depends on the reluctance of the magnetic circuit.

For reactance coils with air-gaps in the magnetic circuit, practically the entire magnetomotive force is concentrated on the gaps, since the reluctance of the iron parts of the circuit is relatively so small that it may be neglected. For the gap,

$$Flux = \frac{m.m.f.}{reluctance} = \frac{\frac{4\pi}{10} IT}{\frac{l_g}{A_g}}$$

Where l_g and A_g are the length and sectional area of the gap respectively.

This becomes

$$H = \frac{4\pi}{10} \sqrt{2} \frac{2}{2.54} \frac{IT}{l} = 0.7 \frac{IT}{l_g} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

When H is expressed as the maximum value of the flux density in the air-gap and l_g is expressed in inches. In the gap the flux fringes out approximately as shown in Fig. 3, and therefore

$$H = \frac{ab}{(a + l_g)(b + l_g)} B$$

Where a and b are the dimensions of the iron section at the air-gap and B is the maximum value of the flux density in the iron. This expression may be put into the form,

$$H = \frac{ab}{l_g (a + b) + ab} B$$

if l_g^2 which is a small quantity be neglected. Substituting this value of H in equation (6) gives

$$B = \frac{0.7 \, I \, T}{l_g} \left[1 + \frac{(a + b) \, l_g}{ab} \right] \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

The effect of this fringing is not considerable for small gaps in the neighborhood of one eighth of an inch or less, but becomes an increasingly important factor as the length of the gap increases.

Example—What current will a voltage impressed on a reactance coil such as to develop a flux density of 10 000 gausses in the iron, force through, under the following conditions? $T = 400$; $a = 2.7$; $l_g = 0.1$; $b = 5.4$.

From equation (7):—

$$I = \frac{10000 \times 0.1}{0.7 \times 400 \left[1 + \left(\frac{2.7 + 5.4}{2.7 \times 5.4} \right) \times 0.1 \right]} = 3.4 \text{ amperes}$$

If approximately 1000 volts are required to force 3.4 amperes through a reactance coil, its rating will be $\frac{1000 \times 3.4}{1000}$ or 3.4 k.v.a.

With a given number of ampere turns it is often important to determine the length of the air-gap which will give a reluctance sufficient to prevent the magnetic density in the iron from exceeding a specified value. For this purpose equation (7) may be put into the form,

$$l_g = \frac{1}{\frac{B}{0.7 \, IT} - \frac{a + b}{ab}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Example—What is the length of air-gap in the magnetic circuit required to give a flux density of 10 000 gausses in the iron, under the following conditions? $IT = 1400$; $a = 2.7$; $b = 5.4$.

From equation (8):—

$$l_g = \frac{1}{\frac{10000}{0.7 \times 1400} - \frac{2.7 + 5.4}{2.7 \times 5.4}} = 0.14 \text{ inch}$$

In general if the voltage of a reactor is not required to vary directly with the current for values considerably in excess of its normal full-load current rating, the coil with an iron magnetic circuit will be cheaper. The iron magnetic circuit reactor also has the advantage that the magnetic flux is confined to the iron circuit, while the air coil sets up a strong field in its immediate neighborhood.

The design of the reactance coil for a minimum cost, with the iron and copper working densities fixed, is worked out exactly as for a transformer; taking into account that the volume of the air-gap is to be subtracted from the total volume of the magnetic circuit.

Industrial Controllers-XXI

Cranes

H. D. James

CRANES are used for hoisting and lowering heavy weights and for moving them short distances. Practically all power cranes are now operated by electric motors. Some small sized cranes are operated by hand, but the convenience of electric power and its almost universal distribution have led to its use even on the smaller cranes.

The best results are obtained with direct-current series-wound motors. These motors have a speed-torque characteristic which gives fast operation on light loads and enables the motor to adapt itself to the load requirements in the best possible manner. Where alternating current only is available, slip-ring induction motors prove satisfactory and there are many cases where the difference in performance between direct and alternating-current motors would not warrant the introduction of converting apparatus.

All types of cranes have a hoist motion and traveling cranes have a bridge and trolley motion in addition. Other forms of cranes have their particular form of translating motion in addition to the hoist. By far, the largest number of electrically operated cranes are of the traveling crane type.

When the crane was operated from the steam engine through the medium of shafting and clutches, it was necessary to provide a load brake to retard the lowering of the load. This brake made it necessary to exert power in the lowering direction to make the load descend. These load brakes are of a very ingenious construction and usually arranged so that the friction load is proportional to the load on the hook. When the electric motor was substituted for the line shafting and clutches, this load brake was retained and a plain reversing controller was used. A further study of this problem showed that the series motor could be connected as a shunt generator when lowering, thereby eliminating the load brake and saving power. This change was introduced about 1910 and has since become universal practice on all new crane equipment.

All hoisting motors have a friction brake mounted on the motor shaft. This brake is released by a magnet when the motor is operated. The brake winding is in series with the direct-current motors and in shunt with alternating-current motors. In some cases an additional brake of this type is placed on the secondary shaft, the double brake equipment giving added insurance against dropping the load. The motors operating the trolley and bridge are usually stopped by plugging or reversing the motor. The movement of the trolley is slow and no difficulty is experienced in handling it. Usually the bridge is equipped with a foot brake which may be used instead of plugging the motor or as an added safety feature should anything happen to the electrical equipment.

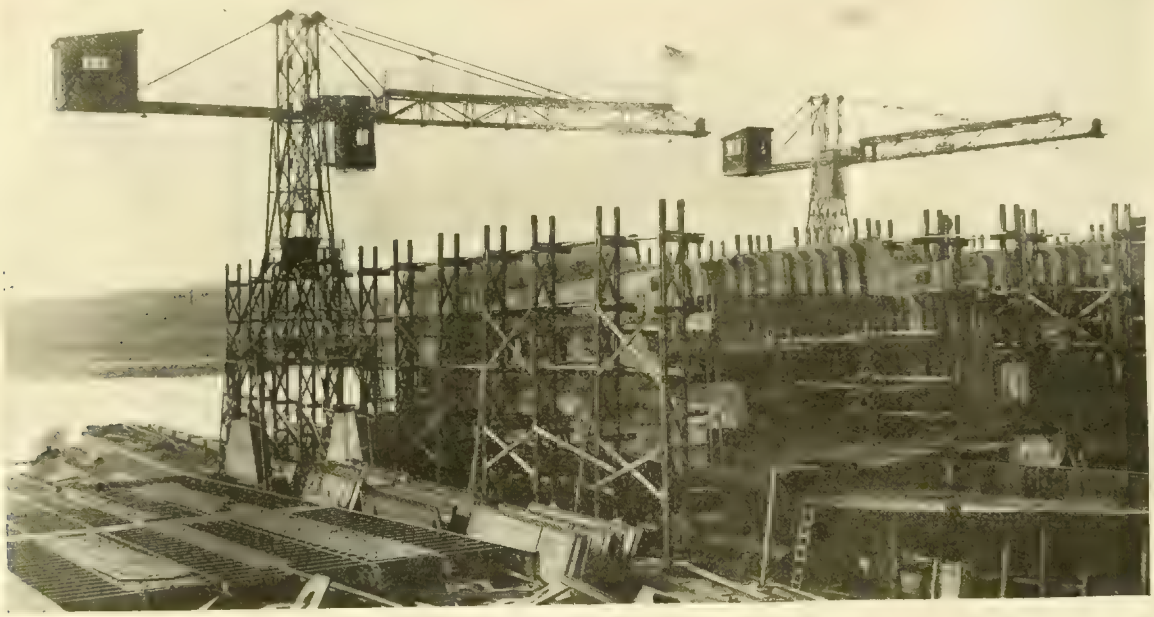
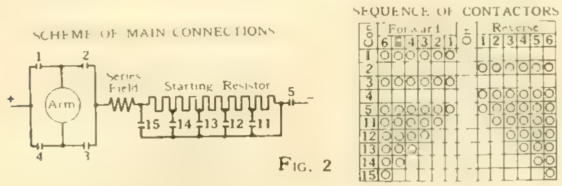


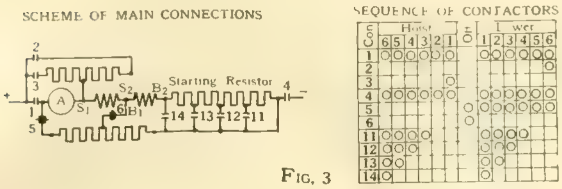
FIG. 1—SIX-TON, HAMMER-HEAD TYPE SHIP-BUILDING CRANE

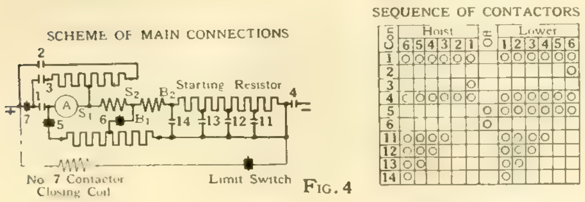
The crane travels on tracks and has a portal sufficiently high to span a box car. It is equipped with 20 hp hoist and crane-travel motors and 5 hp racking and revolving motors. The crane is 58 feet from track to bottom line of boom and 80 feet from center line of portal to end of boom.

Small cranes are frequently operated from the floor. The controller is provided with a spring for returning it to the central position and ropes are attached to an operating wheel or sheave on the controller shaft so arranged that the operator can control the motors by pulling one or the other of these ropes from the floor. Larger cranes have a cab for the operator. This cab is attached to the bridge and contains the control equipment. Some very large cranes have the cab attached to the trolley. This is known as a "man trolley".

The scheme of control is shown diagramatically in Fig. 2 for the hoist and Fig. 3 for the bridge or trolley. Various schemes of control have been devised for the hoist, that shown being in most general use at present. The diagrams indicate a contactor form of control but the same connections may be made with a drum controller. Drum controllers are in common use with the smaller cranes and magnetic contactor controllers on the larger cranes. The dividing line is roughly about 50 hp, but the class of service and frequency of operation are the determining factors. The magnetic contactor control is more durable but also more expensive and takes up additional room. When a manual controller is used, either of the drum type or some other design, it is desirable to provide a protective panel for each







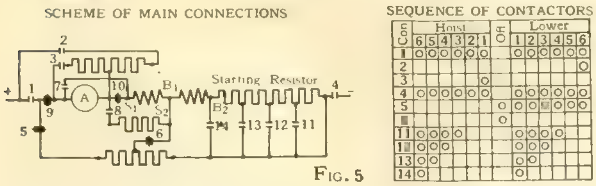


FIG. 2—CONNECTIONS FOR HOIST CONTROLLER
FIG. 3—CONNECTIONS FOR BRIDGE OR TROLLEY CONTROLLER
FIG. 4—CONNECTIONS FOR A HOIST CONTROLLER
With an electric limit switch.
FIG. 5—CONNECTIONS FOR A HOIST CONTROLLER
With a mechanical limit switch. Switches No. 7 and 8 are normally open and No. 9 and 10 are normally closed.

crane. One of these panels is shown in Fig. 11. It consists of a slate panel having mounted on it a knife switch, two single-pole contactors, one overload relay for each motor circuit, and one relay in the common return wire. This latter is called a "totalizing relay" and sometimes two of them are furnished, one for each side of the line. These relays provide automatic overload protection for each of the motors, as well as for the complete system. The knife switch is provided with means for locking it in the open position so that an attendant may lock the switch open when he is working on the crane. Each controller may be provided with a contact for resetting the relays when the handle is in the *off* position or a reset push button may be used.

It is desirable to provide a means for limiting the upward travel of the crane hook. This is usually done by a limit switch. The diagram in Fig. 4 shows the connections for an electrical limit switch using a contac-

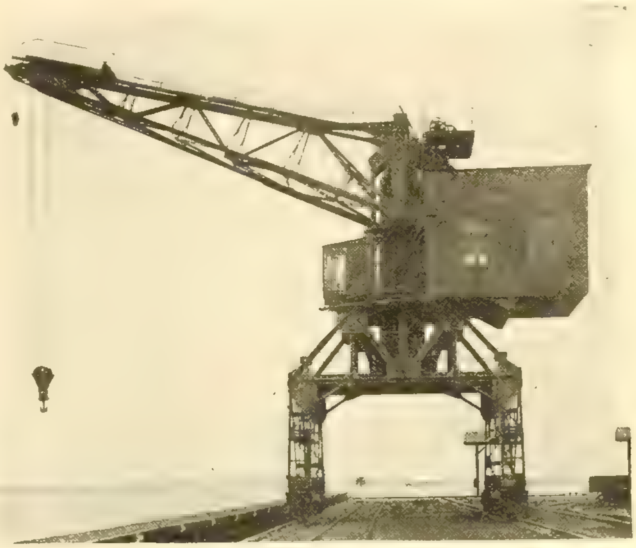


FIG. 6—75 TON FULL-PORTAL CRANE*
This crane has a 54 ft. radius and is 54 ft. from track to pivot pin. Hoist motor, 80 hp; crane travel motor, 25 hp; rotating motor, 33 hp.

tor and Fig. 5 for the mechanical limit switch. These limit switches may either be geared to the hoisting drum or operated by the hoisting block through mechanical means. The limit switch corresponding to the diagram in Fig. 5 consists of a rotating shaft having a quick make and break attachment. When the shaft is rotated through a given angle, the movable element of the switch is snapped from the normal position to the emergency position, which disconnects the motor from the line and applies dynamic braking. When the hook is lowered a short distance, a weight or spring moves the shaft back to its normal position and the switch is snapped back, establishing the regular connections.

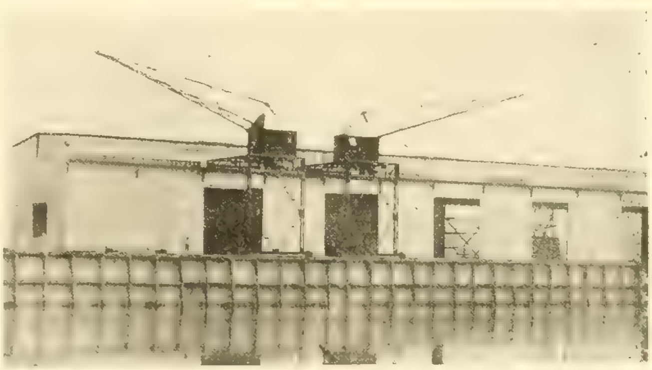


FIG. 7—1.5 TON SEMI-PORTAL CRANE
This crane is equipped with a 33 hp hoist motor; 15 hp crane-travel motor and 7.5 hp rotating motor.

The magnetic contactor control consists of a slate panel having mounted on it the magnetic contactors, knife switches and overload relays. No protective panel is used in connection with this form of control, as the safety features are embodied in the controller itself.

*Cranes shown in Figs. 1, 6 and 7 built by Heyl & Patterson.

The master switch usually consists of a small drum type controller mounted in front of the operator. The contactor panel itself is usually mounted in the upper part of the cab above the operator's head. This requires a longer cab than is necessary with the manual controller.

The most common form of manual controller is of the drum type. This gives a very convenient and compact form of controller but one which is subject to considerable wear for the larger sized motors. In order to provide a more durable form of manual controller, various forms of face plate and grindstone types have been devised. These controllers are usually quite heavy and have a great many exposed parts which endanger the operator. Recently some attempts have been made to cover up these controllers, but this has added to their bulk so that fewer of them are used than formerly.

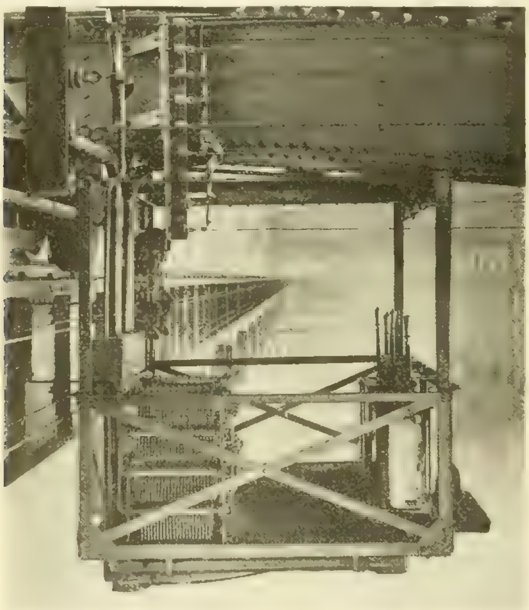


FIG. 8—OPERATOR'S CAB OF A TRAVELING CRANE
Showing cam controller and crane protective panel.

A new form of controller is being manufactured which embodies many of the good features of both the drum type and the contactor type of controller. It is mounted in the form of a drum controller and consists of a series of contactors operated by cams, the cam shaft taking the place of the drum cylinder. One form of this controller is illustrated in Fig. 10. The operation of a cam contactor is shown in Fig. 9. The contacts are made in the same manner as with a magnetic contactor and the same contacts are used, which makes the parts interchangeable. The same blowout is used so that the rupturing of the arc takes place in as efficient a manner as the ordinary magnetic contactor. The cam gives a quick motion for opening and closing so that it is difficult to just touch the contactor. On account of the contactors moving in a horizontal plane and the air space being restricted by the drum mounting, these controllers are not recommended for as large motors as the magnetic contactor type. They form, however, a very valuable intermediate step and may be used even with the smallest motors, as they are available in small sizes. The controller itself is lighter than a drum controller and the construction is such that various combinations can easily be obtained; for instance, the plain reversing controller for the bridge ser-

FIG. 9—CAM CONTACTOR
Showing contacts open, beginning to close and closed, illustrating the rolling contact.

vice differs from the hoist controller only in the cam shaft, the balance of the controller being the same. The bridge motion controller can be used for either alternating or direct-current motors by simply changing the connections. Where alternating-current motors are used, dynamic braking cannot easily be obtained so that the load brake is still used requiring the hoisting motor to be operated under load when lowering. This makes the alternating-current controller the same for the bridge and trolley motions. The cam controller can be connected to the alternating-current motor to start up with single-phase secondary, which gives a small starting torque and corresponding slow speed for light loads. For the bridge service, the same controller is used with both phases closed on the first notch. The adaptability of this design of controller and the use of interchangeable parts with the magnetic contactor control will reduce the spare parts carried in stock. The rolling contact is acknowledged to be the best by all engineers and it should be used wherever possible.

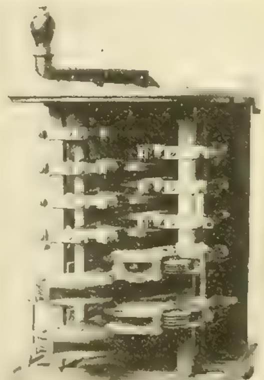


FIG. 10—CAM CONTACTOR TYPE OF DRUM CONTROLLER

FIG. 11—CRANE PROTECTIVE PANEL

The present demand for cranes is very great on account of war work, which has focused the attention of engineers on this apparatus, and many improvements are being made in the design of cranes and the electrical equipment for them.

A good example of a special design of heavy cranes is illustrated in Fig. 12. This shows a 150-ton electrically-operated revolving pontoon crane, which is perhaps the largest ever constructed in the United States. The pontoon contains a complete boiler plant and an engine-driven generator, which supplies the electric current for operating the various motions of the crane. The crane is controlled from a small house mounted above the pontoon deck by means of master controllers; one operator is able to control all of the motions of the crane. When the load is lowered, the motors operate as generators and, in case of accidental interruption of electric current, the crane motions are automatically locked by means of friction brakes to prevent the possibility of dropping the load. The crane motions consist of a main hoist of 150 tons divided into two parts of 75 tons each. These hoists are fixed on the boom. In addition, there is an auxiliary hoist of 25 tons capacity, which is movable up and down the boom. A rotating motion is obtained by two 60 hp motors and the boom hoist is operated from the vertical to an angle of 30 degrees by two screws operated from 60 hp motors. In addition to the crane proper, the pontoon is equipped with four electrically-operated capstans, one in each corner.

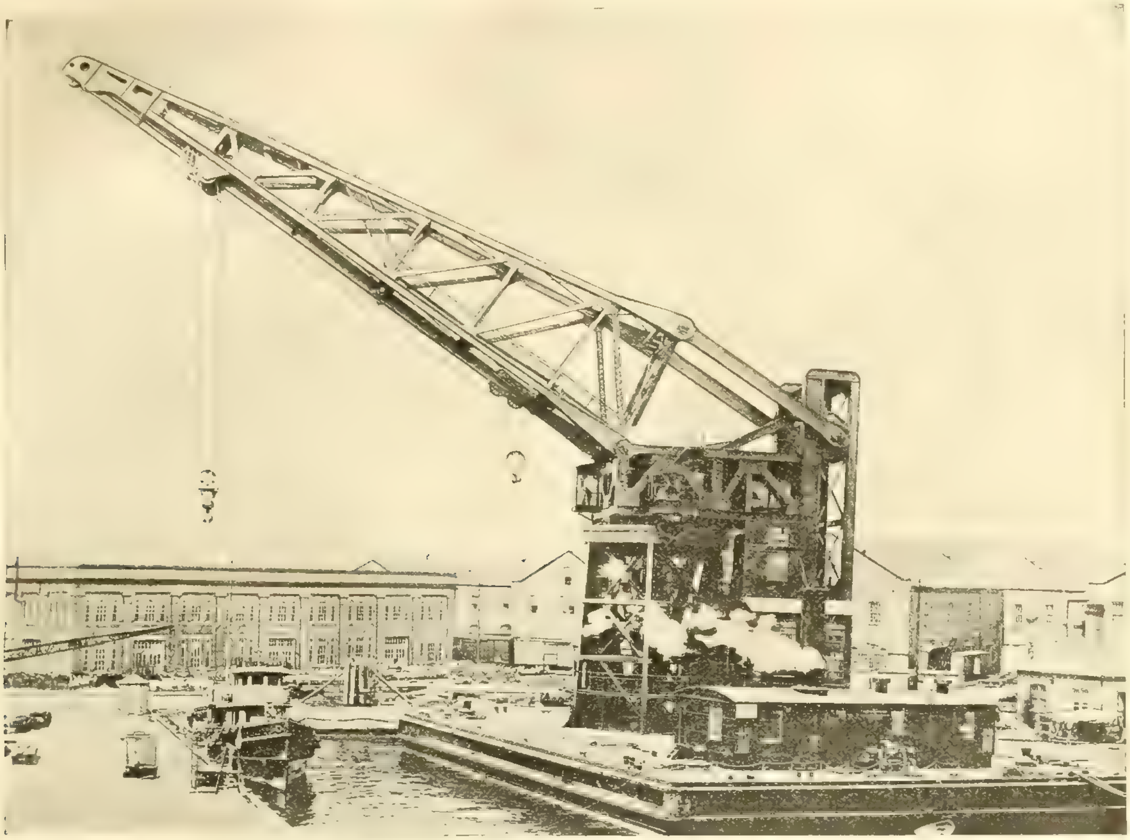


FIG. 12—150-TON ELECTRICALLY-OPERATED REVOLVING PONTOON CRANE*

Pontoon 150 feet by 85 feet and 15 feet depth. Two 60 hp main hoisting motors and one 60 hp auxiliary hoist motor. Two 60 hp rotating motors. Two 60 hp boom hoist motors.

*Crane built by Wellman-Seaver-Morgan Co.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1640—SPARK VOLTAGES—In testing magnetos, under conditions given as follows, we find that we do not get reliable results:—for example, a magneto which will generate a sufficient voltage at 500 r.p.m. and will jump 0.020 inch gap in a spark plug under 75 lbs. to the square inch pressure will occasionally miss fire and will also miss fire if the air pressure is reduced to as much as 60 lbs. per square inch. Then, another condition is met with, this is, that if we use a spark plug insulated with porcelain, and another insulated with mica, although the gap conditions are the same, such as striking distance, material and shape of points, there is a difference in the action between the porcelain and mica insulation. Another case is where the same magneto, passing a test in one shop under a set of conditions, will not test the same in another shop. Such inconsistency makes it very difficult for two inspections at different times to duplicate results. The writer has

made a considerable number of experiments on spark gaps and spark plugs but in spite of these tests has not been able to establish a positive set of conditions by means of which magnetos may be compared and results duplicated. J.G.Z. (ILL.)

In testing high-tension sparks such as are used for the operation of gasoline engines, there are so many variable conditions that we do not believe it is possible to exactly duplicate certain results. We have found from experience that a certain voltage margin is necessary in order to secure operation without missing. For example a spark which will jump a three-eighth inch gap in air will not do so every time, but if there is sufficient voltage to jump this gap it will probably jump a three-sixteenth inch gap without missing. In the case of a spark plug the insulating material used is under an electrical strain and acts as a condenser, and as different materials will give different capacity and effects it is quite likely that this may account for different results obtained with spark plugs using porcelain and those using mica insulation. The effect of the atmosphere around the spark gap also operates to produce varying results as varying percentages of moisture would permit a spark at lower voltage than would be obtained in dry air. Static electricity on the surface of the insulating material of the spark plug may also cause a varying percentage of moisture to be deposited on the insulation and this varying leakage would also tend to produce inconsistent results as considerable leakage allows the induced e.m.f. in the secondary to dissipate itself and perhaps prevents sufficient voltage being attained to jump the gap. For the above reasons it seems to us hardly practicable to obtain exactly similar conditions for testing magnetos and the nearest approximation would be to use the same spark gap, connections, etc. on two magnetos which were being compared. A.H.P.

1642—Railway Armature Repairs—Please state whether (A) or (B) is correct. A Westinghouse 101B railway motor armature was found to have its core one-sixteenth inch out of true in relation to the axis of its shaft. The armature being stripped of its coils at the time, it was decided to fill the slots with hard wood and take off a very light cut in the lathe and finish up with grinding. *A* maintains that this operation has ruined the laminations and that core should be scrapped, his reasons being as follows: (1) Undue heating owing to laminations being short-circuited from turning and grinding. (2) Weakening of the grooves in the teeth which hold the wedges in place. (3) Increasing the air-gap by decreasing the diameter of the armature core and thus affecting the efficiency of the motor. *B* is convinced that this operation is one that is regularly done in cases of this sort, claiming that:—(1) With careful grinding, laminations will not be short-circuited, to any great extent, and that where short-circuits occur they will be local, and that increase of eddy currents will be very small. (2) Grooves for holding wedges will not be affected. (3) Difference in air-gap will not be great enough to be noticeable and that in any case the air-gap would vary this much with any armature on account of the armature bearing wearing. C.A.C. (BRIT. COL.)

Turning down the core and then grinding would undoubtedly tend to set up eddy currents in the surface of the core. Cases have been known of high speed alternating-current machines in which losses caused by this condition have been objectionably high. They would be objectionable in the No. 101-B motor, but it is doubtful whether the increased heating, especially since it is near the surface of the armature, would warrant scrapping the core. The use of a coarse file would be better than grinding, as this would tend to break up the eddy currents and reduce the heating. Grinding of the surface of cores is standard practice in many alternating-current low-speed railway motors and is necessary where a close adjustment of air-gap is required. The increase in the air-gap would not seriously affect the operation of the motor in service, because the air-gap, being only one portion of the magnetic circuit, the percentage increase in speed would be small, and would be in the order of the variations in speed which occur due to variations in castings. The weakening of the grooves for holding the wedges would, we believe, not be serious. It would be well to carefully investigate the cause of the core being off center, such as bent shaft, loose laminations, etc. In the event of something being radically wrong, the turning of the core might only prove remedial, but not finally corrective. F.W. McC.

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The Street Railways in War Times

JOHN J. STANLEY
President,
American Electric Railway Association

The street railway industry has been hard hit by this greatest of wars. In common with all other industries it has faced unusual problems of men, material and finances. Unlike most industries, however, it was ill-prepared to meet them. The years immediately preceding our entrance into the war were not years of unexampled prosperity; on the contrary they were, in the main, disastrous years. Traffic losses with burdensome and mounting costs of operation were already old questions when the war brought new ones.

That the selective service has drawn heavily on the industry is the highest compliment that could be paid it. We are proud that the Government has need of and has requisitioned so many of our men. Future requisitions will make universal one great change in the industry, namely; the employment of women.

A second and greater change is just as certain to come; an unparalleled increase in costs will be met by new revenues. It may be that as we have followed the example of European operators in employing women, we shall also adopt their principle of zone fares. Possibly a straight increase in our present rates of fare, or a modification of the unnecessary and illogical burdens that are now laid upon us may suffice, but certain it is that the industry, which has proven itself essential and necessary to the public, will not be long handicapped by inadequate revenues. The government that has found time and ways to keep business generally at better than usual, while worthily conducting its own business of winning this war, will, in good time, deal justly with our problems, as it has with others.

Facts vs. Theories About Transportation

CALVERT TOWNLEY
Assistant to the President,
Westinghouse Electric & Mfg. Company

We are passing through a period of unexampled prosperity. Every industry having even moderately skillful management, except those classed as non-essential, is now more profitable than it ever has been. In the midst of this golden harvest the railroads and the trolleys almost alone have been starving to death. They used to be among our most prosperous corporations. They are so no longer. Obviously something must be fundamentally wrong either with railroad and trolley management or inherently with these activities themselves.

Measured by the capital invested and the volume of receipts the railroads are our largest enterprises. They have been able to pay and they have paid salaries sufficient to comand the best available talent and it is notorious that railroad executives as a class rank near the top in integrity, ability, initiative and foresight. When occasionally transferred to other occupations they have almost uniformly scored successes of a high order. It can hardly be successfully contended therefore that anything has been fundamentally wrong with railroad management. What I have said about the railroads applies to a large extent to trolley properties as well. Their executives very generally rank among the leaders in their respective communities.

If the trouble is not with the management, then where is it? The traffic is large and has steadily increased. Competition is even less than it was when the roads were prosperous. With good management, plenty of business and not abnormal competition—why are the railroads starving in a land of plenty? The answer is easy, short and anything but sweet—"regulation". The railroads and the trolleys have been "regulated"—industry in general has not. The regulated activities have steadily gone down hill, the others just as steadily have climbed. In plain English *regulation has failed.*

At about this period in the discussion some one usually interjects, "Well, if we don't have regulation then we will have government ownership, would that be preferable?" This of course is not an argument. It is a retort. It reminds one of the footpad who says, "Would you rather give me your money or have me beat out your brains?"

There can be no logic to compel the adoption of one economically unsound plan because some other plan is also unsound. It may be true that we are approaching government ownership. If so, that proves nothing. We went wrong when we adopted regulation. It is quite conceivable that we might make another and even a worse mistake next time. But if we do it will not be primarily because regulation has brought misfortune but because we as a nation have not learned to make the proper deductions from that failure. Therefore, it behooves all of us who are specially concerned or interested to spread the gospel of sound economics and to do what we can to educate the public towards safe and sane views.

Now what had all this to do with trolley road financing? Just this—None of the plans now being pro-

posed or tried, such as the raising of trolley fares here and there, the creation of zones, the operation under elaborate contracts for "service at cost" are solutions. All these simply are more or less skillful attempts to get along somehow under the present fundamentally wrong conditions and it is futile to attempt a satisfactory solution unless and until these facts are recognized and some new and sound economic basis is established. There is grave danger that our transportation agencies will be looked upon as completed affairs requiring only efficient and skillful operation in transporting passengers and freight and not as they actually are, as only partially developed agencies requiring keen foresight and courageous initiative so that their relative value to the nation may continue to be as great in the future as it has been in the past. Government regulation as it has been practiced has throttled growth and driven away prosperity. Government ownership, judged by the uniform effect in every other country where it has been tried, will effectually stop growth and set up a deficit so that the general public and not the user will foot the bills.

Let us hope that we all being educated to know the facts and that one of the blessings which will come out of this world catastrophy through which we are now struggling will be a better understanding of the fundamental facts and a willingness to work in accordance with, and not to attempt to overthrow, basic economic laws.

Mutual Respect and Co-operation Essential

Theodore P. Shonts
President,
Interborough Rapid Transit Company

This is war-time. All peace-time considerations are altered not only in statecraft but in business. The electric railway men of this nation feel keenly a sense of responsibility for the efficiency of service which is so important a part of the national program. They are faced by many a difficulty, but they are responding in a splendid whole-hearted manner to the national call. They are not only pledging their business but their men are going to the war front.

Theirs is not a business that has benefited by the war. No other business possibly has suffered so much from the war. Costs have risen by leaps and bounds, yet their fare, for the most part, has been legally fixed at five cents. Every electric railway man knows the intimate relationship between fares and good service. It is so elemental that they cannot understand why it is not as clear and as simple to everyone as it is to them. But the fact is that it is not; and that is our problem—a problem of bringing the public to realize the true facts.

And we must approach that problem with faith. Faith in the foundation principle that *when the public knows the facts* it will not only be fair, it will be generous. We must have faith. We must take our troubles to the public with faith and confidence. Nothing will serve but the plainest, frankest, most straightforward presentation of the real facts. "Be sure you're right, then go ahead."

The most important aspect of the electric railway problem at the present moment is that of labor. Without competent labor the electric railway is as a body without life. "The laborer is worthy of his hire." It matters not whether a business is profitable, a laborer is entitled to good wages. A wage cannot be fair if it does not meet the rapidly increasing cost of living. Service cannot be efficient without trained forces. To keep trained men the utilities must be able to pay them wages which will meet the competition in other lines.

The public must understand that it should pay. Indeed it cannot escape, for any long period, paying at least the cost of service, including a fair return on the money invested. I know of no better expression of this thought than that in a recent article in *The Survey* by W. L. Ransom, chief counsel of the Public Service Commission of the First District of New York. He says:—

"The public is coming to realize, tardily but surely, that whether the form of ownership and operation be public or private, the public can have, in transportation or public utility service, only what it is willing to pay for; and that there is no way of getting something for nothing for the public from a public utility *over any considerable period of time.*"

In these days the electric railway men are asking an increase of income not for the purpose of raising dividends but in order that the cars may continue to run. Public utility service is a co-operative enterprise in which the utility and public must join. The public utility must have full faith in the confidence that the service will be paid for, otherwise it cannot be rendered in the whole-hearted spirit which alone can make it good. Neither public nor utility should feel that the other is a mine to exploit. Each should feel that they should work together in producing the service that in war-time is needed more than ever.

Undoubtedly there is a much better public understanding of the public utilities than ever before. A clearer perception of our relations will beget the mutual respect and co-operation which are absolutely necessary to the salvation of our nation.

Joint Interest of Manufacturer and Operating Companies in the Electric Railway Industry

H. D. Shute
Vice-President,
Westinghouse Electric & Mfg. Company

The splendid manner in which the American people responded to the Nations needs in these war times, again proves the statement frequently made in past years, that our people are eminently fair and generous when they understand a problem. It is, therefore, proper to assume that the people in many parts of the country, who have apparently been very unfair toward their local street railway companies, do

not understand the financial embarrassment confronting the railway companies. Experienced observers know that the men engaged in the electric railway industry measure up to the high standard of ability of American men of affairs. The cause, therefore, for the present financial predicament of most street railways lies somewhere else; without, rather than within themselves.

There are some conditions brought on by the war which will have to be borne with as such, but the attitude of the people generally toward the street railway industry should be corrected. This attitude seems to be the fundamental difficulty in the way of a speedy and needed solution of the problem. The people must be shown that a progressive and prosperous street railway is just as essential to the prosperity, comfort and growth of their community as the other utilities, such as water, gas, lighting, power, police, fire department, parks, boulevards, etc. The street railway affects the comfort, convenience and welfare of the great majority of the people in every community two or more times each day. It is fair to assume that if the majority of the people appreciated this fact fully, they would change their attitude toward the street railway companies.

The daily press, as a rule, reflects public opinion as disclosed by the action of various semi-public bodies. We have seen many instances, in which an increase in fare was requested during the past year, where the numerous boards of trade and merchants associations of all kinds immediately met and passed resolutions condemning the plan, as well as making further criticisms of the railway companies. The press promptly gave prominent space to such collective sentiment. This public criticism, obviously, is a great factor in creating unfavorable opinion among the masses and, when it is realized that most of these associations are comprised of business men, it would appear to be very essential that the business men representing the manufacturers engaged in the electric railway industry, as well as representatives of the railway companies, should be members of all such important bodies and assume the task of fully explaining the situation; openly and frankly discussing the problems confronting the railway companies.

The manufacturers have a common interest with the operating companies in the electric railway industry. Both are vitally interested in its development and growth. All engaged in the industry appreciate the great factor the electric railways—urban, suburban, and interurban—have been in the wonderful progress and development of our country. The manufacturers and operating companies should establish ways and means for closer and more effective co-operation in building up a more favorable and a fairer attitude on the part of the people toward the electric railway business. The electric railways should not be allowed to drift into bankruptcy and general deterioration and chaos during the war, as they are very essential to the continued growth, comfort and prosperity of the nation.

Prompt Relief Needed by the Electric Railways

M. C. Brush
President,
Boston Elevated Railway Company

Notwithstanding the elaborate system of laws, rules, regulations, orders and decisions for the purpose of supervising and controlling each and every detail of street railway operation through the action of various commissions, boards and other public authorities, the industry has broken down under the abnormal pressure of wartime conditions. There is unquestionably a failure on the part of a great many persons to appreciate the seriousness of the present situation. With an investment of approximately six billion dollars for the purpose of furnishing urban and interurban transportation, and with substantially the entire industry in bankruptcy, surely there should be a full realization of the imminent danger of its complete collapse and the increased serious effects of such a collapse on industries engaged in war time activities.

The five cent fare was never able to provide sufficient revenue to properly care for depreciation, obsolescence, a fair return on money invested, and a reasonable surplus for emergencies. It has been necessary, when a company has desired to revise its tariffs, to file with the proper commission or board its proposed schedule of new rates. This commission then held public hearings and usually, after a considerable lapse of time, during which the burden was added to, it authorized the whole or a part of the proposed changes, as it saw fit. No matter how self-evident or immediately pressing the necessity for changes may have been, none could be made until after long and protracted hearings, examinations, investigations, etc. While there is no reason against, and every reason for, all the parties in interest having all the time and facilities necessary for a proper analysis of a given case, nevertheless the patient should not be assumed by the doctor to be well regardless of what the patient says about his sufferings, while the doctors listen for weeks and months to the evidence of those trying to diagnose or learn the patient's ailments and become experts before permitting the doctors to prescribe the imperatively needed remedy.

Unquestionably the present system of regulations and supervisions has contributed to the collapse of this industry, and the fact has too often been lost sight of that the interest of the transportation companies and the interests of the public are essentially mutual and identical, and that neither can afford, in the long run, to be served in any way by the sacrifice of the other. This part is, of course, elementary. The power of supervision and regulation, without responsibility for the administration of the particular property, has gradually but effectively so stultified the industry as to make it too weak to serve now, in any virile sense, the purpose for which it was created and intended. The slogan of the Hog Island executive, "Let us build ships now, and

put us in jail afterwards if you wish" equally applies to the street railway industry as it exists today.

The American people as a whole are fair, and when the facts are substantially put before them they are pretty sure to agree that a man must be permitted to have a voice in the management of his savings. Doubtless, in the long run, and with more enlightenment and a full presentation of all the facts, the industry will receive a square deal, but now is not the time to spend months, weeks or even days discussing what has, or has not taken place in the past. The immediate job in hand should be to take care of the present critical and alarmingly acute situation and provide and plan for the future. Post-mortems can wait but the adequate maintenance of transportation is an ante-mortem necessity and cannot wait, and should not be expected to. Every one should put his shoulder to the wheel and with a broad intelligent view produce that which is absolutely essential to the furnishing of the material for the successful conduct of the war and the greatest possible comfort of the boys in France—first class urban and interurban electric railway transportation. The entire country is suffering this moment for lack of absolutely necessary transportation facilities, and it is doubtful whether any temporary relief will meet the situation, for permanency as well as efficiency of any relief is needed to bring back promptly to the industry the much scared, timid and impoverished investor and operator.

A full realization of the imminent danger and the seriousness of the situation, by the hundreds of thousands of citizens directly or indirectly concerned, and of the importance of giving adequate railway transportation, should be the starting point for an aroused public sentiment for the most prompt and efficient relief that can be secured. Palliatives, inventories, studies and surveys are of no value to avert the impending catastrophe, for surely the collapse of a six billion dollar industry is a national catastrophe, and it would seem that one of two methods must be promptly followed. Either the national government must promptly take over the complete operation and administration of all electric railways, as it has in the case of the steam railroads, with an executive power in Washington for electric lines, equivalent to that power now vested in Washington for steam lines, or else the states, cities or districts interested in the maintenance of service must promptly so guarantee the return on investments that the companies may do such financing as will make possible efficient service and enable them to meet the trying and extraordinary burdens now being placed on the industry. There are 47 000 miles of street railway track in the United States as against 331 000 miles operated by steam railroads. Surely Government intervention is needed to prevent the bankrupting of the companies operating one-eighth of the total mileage, both steam and electric, in the United States, in the middle of a great war, with the possibility of discontinuation of operation or junking or tearing up of a large portion of the trackage.

It is obvious that nearly every street railway is parting with its very life blood and the continuance of its industrial life is absolutely dependent upon prompt and efficient measures, if it is to continue its transportation service. Every person interested in street railway success, whether he be employe, official, investor or connected with the manufacture of materials and equipment used by street railways, is dependent wholly or in part upon the street railway for his daily bread. Such persons can be made to feel a personal interest in working out the problems, but should also be led by self-interest to give all possible assistance in bringing about a speedy termination of the difficulties. Through such persons as these a great deal of pressure can, and should be brought to bear in order that one of the two remedies above suggested, or some other equally effective one, may speedily be applied to the situation, and the street railways saved from disaster.

Service and Co-ordination

F. H. Shepard
Director of Heavy Traction,
Westinghouse Electric & Mfg. Company

In these momentuous days there is not a red-blooded American who would not prefer above all else to be chasing Huns with the business end of a bayonet. But victory does not depend on front-line forces alone and those of us that must stay at home have our own work cut out for us to increase the productive ability of the nation to place its resources at the disposal of our heroic fighting men. This is no light task and it presses especially heavily upon the electrical men of America. Not without reason are our times known as the "Electric Age", and if we, who produce and apply this power, should underestimate our responsibility, the result would be disastrous. Furthermore, since we are the creators of a new art and science, our daily lives are devoted to abstract thinking and to the solving of new problems and the over-coming of hitherto unknown difficulties. Hence we should feel ourselves among the leaders of modern progress and should bear a greater burden of service than the majority of our fellow men.

The present obligations of every class of men are well-marked. That of the electrical fraternity is to *conserve*—to save fuel and materials, by the exercise of our utmost engineering skill; to save that priceless factor—time—by helping to expedite every step of the nation's industrial operations; and above all to save human labor, by multiplying by ten, a hundred, or a thousand fold the power of each pair of human hands.

The events of the past year have been graphically described as a race between President Wilson and Field Marshall von Hindenburg. Wilson won, and to the past efforts of the electrical men a share of the credit for this is due. But the greater work, that will mean added sacrifice, is yet before us and our thought today must be upon our responsibilities and the part that each one of us must play. We can not, however, achieve success alone, but only through co-ordinated co-operation. This is the great lesson we have learned from the

war. Theoretically, we knew it before, but practically we worked solely for our own interests. Now we realize, with that clearness that bitter experience best imparts, that we can no longer stand isolated as a nation, as a class or as individuals. In politics we must think in international terms; in commerce and industry, we must no longer work selfishly, as the Germans do, but aim at the greatest good for all.

Time was when, in commercial relationship, the buyer, the seller, and the seller's competitor were in conflict for the improper advantage of one over the other. Now we know that all must work in harmony and mutual confidence for the best interest of each, of the industry and of the people.

We are in this war to prepare a brighter future for those who come after us—to insure equality of opportunity—a "square deal" for all. We now know we are all partners in this program—capital with labor, manufacturer with customer, public service corporation with the public; and unless this great partnership continues to exist after the Hun is crushed, we shall have lost the best that has come out of this hell of bloodshed and destruction.

All honor to the electrical man who lays the wires at the heels of the charging troops and who repairs them in a murderous storm of steel. But some honor, too, is due to him who, humiliated in spirit, sits safe at home helping to create and maintain that tide that is sweeping onward to victory. And dishonor be his, if he takes a step backward after the boys at the front have come home.

Adopt a Model Franchise

RICHARD I. SULLIVAN
General Manager,
Mahoning & Shenango Railway & Light Company

The outstanding fact in the street railway situation today is that service cannot be given much longer for less than cost. Street railway fares must be raised. The power to raise fares does not lie with street railway companies. It is held by various rate making bodies. These bodies must act if the public is to continue to get street railway service. The issue is clear and concise. It is no longer between the public and the management of street railway companies. It now rests between the public and its rate making bodies. When street railway executives have clearly and forcibly presented this fact to the public and the rate making bodies, their responsibility ceases.

The day of the fixed fare for street railways has passed, whether it be a fixed fare of five cents or six cents or ten cents. Railways must have long term franchises to permit them to do their financing. No man can fix a just rate of fare over a long period. Either the fare will be too high and the profits too great or the fare will be too low and the profits too small. The public will be paying either more or less than the cost of a ride. The fare must be made flexible and service sold to the public at cost.

The situation as it exists today offers the industry a magnificent opportunity to get upon a permanent, stable basis. This must be done by each company acting alone but the companies can be wonderfully assisted if the American Electric Railway Association will formulate and adopt a model franchise providing for service at cost, under the terms of which the company will be secure in a fair return on the money honestly spent on its property and the public will be assured of the kind of service it wants. Such a model franchise, properly formulated and properly sanctioned by the American Electric Railway Association, with the indorsement, if possible, of the President of the United States, the Secretary of the Treasury and the Comptroller of the Treasury, would readily be accepted by the various rate making bodies who now are slow to act because of their distrust of the statements of railway companies or because of their political cowardice.

The value of the property covered by a service at cost franchise is the biggest obstacle in the negotiation of such a franchise. To save time, during the period of the war a value of $100 000 per mile could be used tentatively, and if the Secretary of the Treasury would sanction the use of this figure in negotiating service-at-cost franchises throughout the country, the entire situation could be straightened out in two or three months.

The assumption for the above reasoning is that street railway service is essential and that there will be enough riding under whatever fare is established to produce sufficient revenue. If this assumption is not true and if the riding decreases as the fare increases, even when one-man cars are used, the street railway industry is economically dead and either the service must be eliminated or it must be artificially sustained as by (a) restrictive legislation against passenger carrying automobiles or (b) a public subsidy.

Seeking for the Best Railway Motor

B. G. LAMME
Chief Engineer,
Westinghouse Electric & Mfg. Company

It has been said, and with truth, that no development can be brought to its best point without first carrying it too far. This stands to reason, for in any new development we are, as a rule, working beyond existing data and experience and we cannot say where the best point lies until we have gone so far beyond it that we can see that we are losing ground. This is particularly true in electric railway apparatus, for so many conflicting conditions are encountered in railway work that any construction upon which we may decide is almost always a compromise between more or less opposite conditions. In consequence, we must know the limitations rather thoroughly before such compromise can be made and this means that we must obtain data beyond the best conditions.

Those who are familiar with the conditions in electrically-driven street cars, must feel pained at the relatively heavy dead weight of the cars and equipment compared with the average live weight which they

carry. In the past few years a thorough recognition of car inefficiency, due to the small percentage of live weight, has led to very serious efforts toward remedying, or lessening, the defect. Not only has much work been done toward lightening the car structure as a whole, but very strenuous efforts have been made, and are still being made, to lessen the weight and improve the output of the electrical equipment or, in other words, to increase the output per pound. However, in doing this there must be a continual compromise between opposing condition. For example: The service which the electric motor must meet may be classed as normal and abnormal or emergency, and these two services imply radically different constructive conditions in the motors themselves. Normal service may require a moderately small current for relatively long periods; whereas, the abnormal or emergency service conditions call for excessively heavy currents for brief periods, and these two conditions call for quite different motor constructions. For the normal rating the motor must dissipate to the air a moderate amount of heat, at practically the same rate as it is generated. This may be attained by natural or artificial ventilation in the design of the motor. However, when it comes to abnormal or emergency conditions, a very large amount of heat is generated, in fact, very much more than can be dissipated directly to the surrounding air and, therefore, the excess must be stored in the mass of material comprising the motor. As a rule, the more massive, or heavier the motor the greater will be its emergency capacity. In consequence, light weight motors obtained by greatly improved ventilation may be considered as having relatively small emergency capacity. Therefore, any strong tendency toward reduced weight by means of ventilation leads, as a rule, toward a sacrifice in one of the important characteristics of the railway motor.

As stated, in recent years there has been a strong tendency toward reduced weight of railway equipments. As regards the motor itself, this tendency has been manifested principally in the direction of artificial ventilation. Improving the ventilation in a motor either by internal or external means, will increase its normal capacity very considerably, but its abnormal capacity is improved to a very much smaller degree. Therefore, in the application of such motors it is necessary to take into account all conditions of operation to a much greater degree of refinement than in the case of the earlier and heavier motors. In brief, the application must be more carefully made. In some cases where abnormal conditions are controlling, it may not be possible to take full advantage of the full increase in normal capacity and reduction in weight resulting from the improved ventilation, since the abnormal loads may call for a larger thermal capacity than that corresponding to the normal rating. In other cases, full advantage can be taken of the improved normal rating and reduced weight. It is simply a question of properly fitting the motor to the service, and there is no reason for making all railway motors of heavy weight and high thermal capacity simply to accomodate certain unusual cases. The better way is to make the whole line of railway motors as light as practicable for the normal ratings and then pick out the proper size of motor to suit any particular service. Under such an arrangement some railway systems would have to buy heavier railway motors than other systems having the same normal conditions but easier or lower abnormal service. Because some have to buy heavier motors, is no reason why all should be penalized.

When it comes to reducing weight by means of artificial ventilation, another condition enters which may be more or less serious if not properly allowed for, namely, the effects of dirt, moisture, snow etc., which may be carried into the motor by means of the air circulation. If artificial ventilation is carried to the utmost, obviously a considerable amount of air must be blown through the motor and such air must be taken more or less directly from the outside. Dry dust and similar materials may be blown directly through the motor with very little deposit, or if deposited to any extent, may, at intervals, be blown out by high pressure air. Such dust, as a rule, is not conducting and is not generally harmful to the motor. Therefore, if dust and dirt only were to be contended with, artificial ventilation might be carried to the extreme. However, the conditions are quite different when moisture or snow is carried into or through the motor in excessive quantities. This is especially the case with snow, for upon entering the hot motor, it tends to become moist and sticky and is liable to lodge inside in quantities sufficient to be harmful. The past winter furnished many examples of this tendency, largely because of the abnormal season. In many cases snow banked up each side of the street railway tracks to such an extent that the cars ran practically in troughs and dirt or snow stirred up by the car was sucked through the motors.

It may be suggested that an obvious remedy for this condition would be to use covers over the ventilating inlets during the winter. However, if the artificial ventilation is carried to the utmost, such motors can only stand complete enclosure during the coldest weather, and on the first fairly warm day that comes along, there is liable to be very serious heating with the enclosing plates on. Consequently there would be the necessity for frequent changing of the cover plates. If such changes could be made by merely pushing a button, there would be no serious objection to such an arrangement. However, when one considers the trouble involved in frequent removing or replacing of all the cover plates in a large railway system, it may be seen that such an arrangement is not an ideal one. It would appear in such case, therefore, that the construction is carried too far and that a better arrangement would be one in which the normal capacity of the motor would be sufficient, during the average winter weather, with the enclosing plates on, while the effects of the warmer weather, during a large part of the year, could be overcome by removing the enclosing plates. Such a motor,

therefore, would need only to be enclosed during the snowy months, which, in many cases, cover only about three months in the year, while during the warmer weather improved ventilation could compensate for the higher external air temperatures. The whole problem resolves itself into that choice of design which results in the least average trouble, while giving proper weight to the different kinds of troubles which must be taken into account.

The Electric Street Railway Crisis

H. W. Clapp
General Superintendent,
Columbus Railway, Power & Light Company

The crisis in the electric railway utility business which was hastened by the world war seems to have pointed the way to a logical solution. These enterprises to be successful over periods covered by franchises (in the main running for 25 years) must have grants based on the service-at-cost plan. The fare charged should always be sufficient to secure the revenue necessary to cover all operating charges, as well as a fair return on a fair value of the property.

Recent experience with the universal "one fare" on American street railway systems indicates that during a period of high costs such as the present, the one fare is not the answer by which we can secure the necessary maximum in revenue increases. For example, when a 5 cent fare is increased to 6, 7, or 8 cents, the percent increase in revenue is very disappointing, due to the shrinkage in the short haul traffic. This result is a natural consequence. The answer without doubt is to be found in the "section system" of fare collections commonly in use in many parts of the British Empire—not a section system built upwards from the 5 cent fare as a basis for the first or interior section in congested portions of a city, but a section system built up on the basis of a 2 cent section for the first interior ½ or 3-4 mile section and a multiple of outer sections of from 1 to 1½ miles each (varying with the density of population) with a charge of 2 cents each.

Of course with such a system the through rider secures a discount as compared to the case of accumulative sections through which he travels from the first to the last section on any one route. The suburban real estate operator has nothing to fear under such a scheme of fares, for he and his through riders are thoroughly protected. Cities in the British colonies where this method of fare collection has been in operation for many years show remarkable suburban growth and the utilities are financially prosperous, enjoying a considerably greater revenue per car-mile operated than most, if not all of our American cities of equal size. It is a matter of public education and a desperate need on the part of the utilities.

Fare collection under this section system is not difficult or complicated. It has been worked out for us. All that is necessary is to adapt it to our local needs. Transfers must be reconsidered in any case. They have grown into a great evil in many cities and have come to be considered and used by the public as much for round trip riding purposes as for a transfer in the original sense of the word.

One rarely finds an American city that is receiving adequate street car service owing to the fact that the fluctuating cost of the service was not taken into consideration when the selling price of "the car ride" was written into the franchise or grant. In the section system of fare collections, the effect of rising costs is felt much less by the individual rider than with the one fare system. The fare increases on the sections being naturally only fractional when compared with necessary increases on the one fare system. A community should have full control of its street car service through a railway commission appointed by the city and in return the rider must pay for the cost of the service he demands through his appointed commission.

Principles of Economical Car Operation

F. E. Wynne
Engineer in Charge, Railway Application Section,
Westinghouse Electric & Mfg. Company

Certain fundamental principles of economical car operation have been recognized for many years and advocated at irregular intervals by a number of engineers. The seed sown has taken root, developed and produced fruit in some cases. However, sound analysis of operating conditions and consistent endeavor to co-ordinate the best service to the public with a satisfactory return to the investor have not been universal. The failure of some railway operators to appreciate the value of the principles outlined, the timidity or inertia of others, the ignorance of the public, the paucity of real educational publicity, and the lack of confidence and co-operation between the public and the railways have been among the contributory causes. The exigencies of the present situation are accelerating the adoption of some sound practices which help to conserve fuel and labor and at the same time improve the service afforded the travelling public.

The Fuel Administration has taken the lead most effectively in establishing "skip-stop" operation in many communities. Such operation is inherently correct and its practice during the war period will demonstrate its advantages to both the railways and the public so thoroughly that we may expect its extension rather than a reversion to the absurdly frequent stop conditions of former years. On paper and in practice it can be proven that reduction in the frequency of stops decreases the work to be done by the car equipment, the energy required from the power plant, the wear and tear on rolling stock and roadway, and increases the schedule speed. The railway company receives benefits from the resulting reductions in troubles on the road and in expense per car-mile for maintenance and power, and from the fact that on lines of sufficient length fewer cars and crews can maintain the former frequency of

service or the former number of crews and cars can produce more frequent service. The public profits by faster, more comfortable and more frequent service. The maximum reduction in energy consumption is obtained by retaining the old schedule speed after the stops are reduced but there is still a very appreciable economy in the power bill where higher speed is utilized. In general, best all around results for the railway are secured by adopting the faster schedule and thus sharing the benefits with its patrons.

An enormous proportion of the service given by the electric railways is wasteful of power and fuel because of careless and inefficient handling of the cars. Passengers are not encouraged to board and alight quickly, accelerating and braking rates are often below values that are perfectly safe from all points of view, and cars are driven over their routes ahead of schedule and the time gained at the expense of power is absorbed in loafing at the terminals. Various effective devices for securing crew performance approaching the ideal are on the market. At the present time, correct instruction in car operation given the crews should be unusually productive of fuel economy, if coupled with an appeal to their patriotism.

A recent railway development promoting great operating economy and improved service is found in the "Safety Car". Although originally intended as a "jitney-killer", it has not only performed that function admirably, but has demonstrated its eminent suitability for meeting all the requirements of many properties. A very complete and readable description of the operating features of safety cars and the results secured to date is given in the article by Mr. Woods in this issue of the JOURNAL.

Last winter's severe weather was a source of much grief for the electric railways but the experiences of that period will be of general benefit for the future. The troubles due to insulation failures in such stormy weather will be greatly alleviated by the more general practice of dipping and baking motors. Ventilated motors will be better protected against the entrance and retention of water, snow and filth. Although many engineers believe that the struggle to produce motors of maximum weight efficiency has led to somewhat unreasonable designs, it is hardly conceivable that motor design will revert to the unventilated type. The limitations of light weight motors in heat-storage capacity and, therefore, in ability to handle overloads satisfactorily, are discussed fully in Mr. Cooper's article in this issue. The fact that such limitations are inherent to motors of this type introduces new elements for consideration in motor application. Therefore, complete knowledge of all the operating conditions is essential to the selection of the correct motor for a specific service. Recognition of these facts, resulting in a somewhat more conservative selection of ventilated motors, will enable the railways to realize the maximum economy from this development in motor design.

The Fourth Liberty Loan

M. B. LAMBERT
Assist. Mgr., Railway Dept.,
Westinghouse Electric & Mfg. Company

Patriotism—To us who are here at home and on whom the boys at the front must depend for complete support, another opportunity is now given to show our patriotism to the fullest measure by subscribing for Liberty Bonds.

Duty—The greatest reward and satisfaction to all of us is the belief that we are performing our full duty to God, our country, our people and ourselves. Our full duty in this crisis is to subscribe to the utmost of our ability for Liberty Bonds.

Sacrifice—Performing our duty patriotically in these times will undoubtedly entail considerable sacrifice. Yet our boys at the front are making the supreme sacrifice, believing in their hearts that we, at home, will make every sacrifice to support them in their struggle. Think profoundly on the agony of heart these boys will suffer, in addition to what they are now suffering, if we do not provide them with the materials and supplies essential to vanquish the Hun.

We, at home, as a whole, have not been called upon heretofore to make much of an individual sacrifice. To furnish the billions of dollars now needed to support our big army at the front, we must all make great sacrifices. Let us overwhelm the Hun with our determination to win and overwhelm our boys at the front with that priceless feeling of gratitude which gives added courage to their efforts.

Foremost among the big things we can do, is to buy as many Liberty Bonds as possible.

Thrift—Aside from the fact that it is our patriotic duty to support liberally our brothers and sisters at the front, and make every possible sacrifice to do this, our Government has arranged so that it is really no permanent sacrifice to subscribe for Liberty Bonds. As an investment, they are the soundest and safest on earth.

Thousands of men and women today are the proud possessors of Liberty Bonds. They have found that they really do not miss the money. If they had not bought Bonds, the money would have been spent otherwise. We have been marked the world over as a spendthrift nation. Now is the time to correct these bad habits and at the same time do our full share in this fight for Liberty.

Every Liberty Bond we buy gives moral and physical support to the boys "over there" and makes us better and stronger men, morally and financially.

It will be gratifying to us and to them if we can show our full quota of each and every Liberty Bond issue. The more we can show, the greater will be our happiness and contentment in future years.

Develop the habit of thrift and be in a position to prove when the boys come back, that we did our part here at home.

War Time Economies for Electric Railways

Clarence Renshaw

IN REARRANGING the productive activities of the country to provide for carrying on the war with as little real hardship as possible, two of the essential elements are the giving up of luxuries and the elimination of waste. In many ways, we are already familiar with these ideas. We have cheerfully reduced our consumption of sugar, beef, wheat, etc. and have become accustomed to lightless nights, lower room temperatures, upper berths on Pullmans, fewer deliveries from stores and other items of a similar nature. These things have been of considerable importance in a psychological way in bringing the war home to many of us, as well as in a material way, by reducing the consumption of the commodities concerned. Best of all, we have found that while we have had to sacrifice many ideas to which we had long been accustomed, we are really no worse off for the parting.

Many further economies in men and material will undoubtedly be necessary before the war is over, and in looking for opportunities to effect them, the electric railway systems of many cities seem to offer considerable promise. The transportation which these lines afford to ship-builders, munition makers and other war workers, as well as to the community in general is, of course, a service of vital necessity and must not be seriously impaired. There are, however, a number of luxuries and a good deal of waste in connection with the handling of the traffic in some communities, and if the public would allow the railway companies to eliminate some of these, economies could be effected in many cases, not only without interfering with the fundamental service, but with a real improvement.

THE SKIP-STOP SYSTEM

One of the first steps in placing the electric railway in any city on a war-time basis is the adoption of the skip-stop system. At the request of the U. S. Fuel Administration, during the past six months the public authorities in a large number of places have already consented to the adoption of this system by the railway companies. In many of them, however this has been permitted only in part so that the full savings of which the system is capable have not been realized.

On the old basis, the electric cars in the large cities would stop on signal at any street corner. This usually meant that there were about 15 stopping places per mile. With the skip-stop system, the cars stop only at certain marked points and the number of these is limited to six or eight per mile. By this slight change, it is possible ordinarily to increase the schedule speed of the cars 10 or 15 percent and at the same time to reduce the consumption of power and fuel by a corresponding amount. In many cases, the increase in speed permits a proportionate reduction in the number of cars required to maintain the necessary headway and thus carries with it a release of man-power for other essential occupations and a reduction in the equipment required.

It is true that with the skip-stop system a certain number of people have to walk a minute or a minute and a quarter more than formerly from residence or store to the nearest stopping point of the cars. In spite of this, however, with the interval the same, so that one can get a car as often as before, and with the speed increased, so that after boarding the car, one reaches his destination in less time than before, most people will agree that the net result of the change is an improvement in the service.

Business Districts Should Be Included—In some cities, the skip-stop system has been permitted in the residence or outlying districts, but in the downtown section all of the old stopping points have been retained and stops are made there as usual. It is commonly argued, in such cases, that the number of stopping points which could be omitted in this section is so small that the additional economy obtained by omitting them would be out of proportion to the additional inconvenience it would cause the people. This argument, however, overlooks the fact that in the downtown district, 5 or 6 lines frequently operate over any given section of track. In this district also the probability of a car actually stopping at any given stopping point is at least twice as great as in any outlying district. As a combined result, every stopping place which can be omitted in the downtown district is equivalent, from a fuel saving standpoint, to 10 or 12 stopping places omitted in any outlying district served by a single line.

Congestion Relieved in Washington—Every stopping place omitted in the business district also, is of considerable importance in improving the service. Before the adoption of the skip-stop system in Washington, there were six stopping places for northbound cars and eight for southbound in a certain section of the business district approximately 2300 ft. long. This gave an average distance between them for the two directions of approximately 370 ft. During the hour from 4:30 to 5:30 P. M., 111 cars were scheduled to pass through the greater portion of this section, but observations showed that, owing to the congestion, 24 of these cars failed to go through during the hour. The number of stopping places was then reduced to four in each direction in this section with no change in any other part of the city (several months later the skip-stop system was applied throughout the city) giving an average distance of approximately 735 ft. When this change had been made, all cars then went through on schedule. The change, therefore, not only reduced the congestion in the downtown district immediately

concerned, but by releasing cars which had previously been held up there, improved the service over the entire system.

It is obvious that if the opposite plan of omitting stopping places in the residence districts but retaining them all in the downtown district had been followed in Washington, there would have been little or no improvement in the congested section and much of the time gained in the residence districts would have been sacrificed by delays downtown. The same principle holds true in other cases. In applying the skip-stop system to any railway as a war-time economy, therefore, to enable the necessary transportation service to be given to the community in a way which, as far as possible, will avoid waste of fuel and man-power, it is obvious that it should be done completely and thoroughly.

OVERLAPPING LINES A COSTLY LUXURY

Another opportunity for war-time economies in the operation of electric railways in many cities is the arrangement of the routes. One of the luxurious ideas to which the public has been accustomed in peace times is that of through cars, so routed that one can ride from almost any section of city or suburbs to the down-

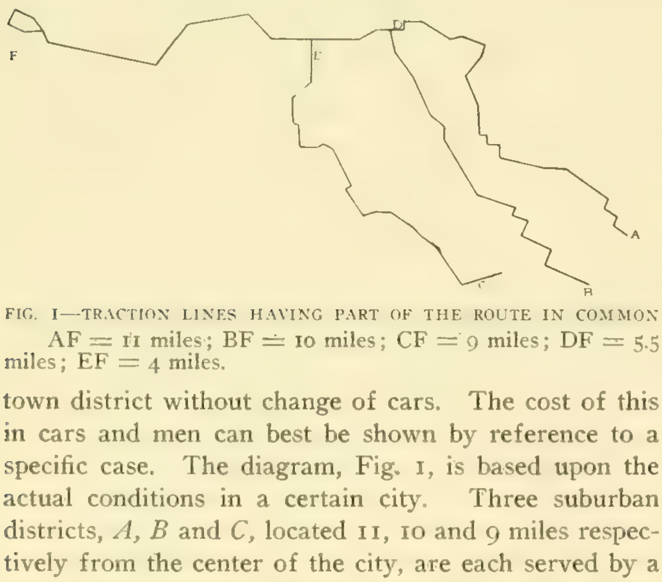

FIG. 1—TRACTION LINES HAVING PART OF THE ROUTE IN COMMON
AF = 11 miles; BF = 10 miles; CF = 9 miles; DF = 5.5 miles; EF = 4 miles.

town district without change of cars. The cost of this in cars and men can best be shown by reference to a specific case. The diagram, Fig. 1, is based upon the actual conditions in a certain city. Three suburban districts, *A, B* and *C,* located 11, 10 and 9 miles respectively from the center of the city, are each served by a line of cars. At *D,* 5.5 miles from the downtown terminus *F,* the lines from *A* and *B* join and at *E,* four miles from *F,* the line *C* also joins. The normal all-day headway is 10 minutes on line *A* and 15 minutes on lines *B* and *C.* The round trip times are two hours and ten minutes, two hours and one and three-fourth hours respectively for the three lines and the number of cars, 13, 8 and 7. The section between *E* and *F* is such that the line *A* alone with ten minute headway, or six cars per hour, would be entirely sufficient to serve it, but on account of the converging of the three lines, there are actually fourteen cars per hour on this four mile stretch.

Great Economy by Small Change—In putting this line on a war-time basis, so as to give reasonably convenient transportation as economically as possible, the obvious thing would be to discontinue the through service from *B* and *C* and transfer the passengers to and from the line *A* at the points *D* and *E* respectively. On this basis, only four cars instead of eight, would be required for line *B,* which would now operate between the points *B* and *D* only and four cars also, instead of seven, would suffice for line *C.* Considering the group of three lines, therefore, there would be a saving of 7 cars out of 28 or 25 percent. Assuming service for 18 hours per day, with three kw-hr. per car-mile at the power house and 2.5 lbs. of coal per kw-hr., the above change should effect a saving in coal of over 1800 tons per year, as well as releasing 28 men for employment in essential war industries.

Service also Improved—While there may be some inconvenience to the passengers to and from *B* and *C* in transferring at the junction points, so that in this respect the change might be said to impair the service, other effects should more than compensate. The operation of only six cars per hour from line *A* in the downtown section instead of fourteen cars per hour from all three lines, as before, would reduce the congestion in the streets (especially if other lines using the same downtown streets were reduced in a similar way) so that the cars which did run could make better progress and keep more nearly on schedule. With the cars of lines *B* and *C* operating only in the outlying districts, where there is little to interfere with them, they too should have less difficulty in keeping exactly on schedule so that in reliability and uniformity of spacing, the operation of all three lines should be greatly improved.

Out bound passengers waiting anywhere in the section *EF* for a car to *B* or *C* would be able to take the first car which appeared instead of having to let perhaps three cars pass (two of line *A* and one of line *C*) before the right one came, as would frequently happen with the through car system. This would not only produce a good psychological effect, but as a car would appear every 10 minutes instead of every 15 minutes, it should save time. Alternate cars could make a direct connection at the transfer point so that there would be an even chance of saving five minutes compared with the old arrangement, while at the worst, the trip should take no longer than before. On the inbound trip, there might be a few minutes lost in transferring, but broadly speaking, with the details properly carried out, it should be entirely possible to secure this large saving in men and fuel as an aid to winning the war, while still maintaining ample service.

Another Example of Overlapping Routes—A more complex example of the same sort is shown in Fig. 2, which also is based upon the actual conditions in a certain city. In this case, an effort has been made in routing the cars, not only to enable passengers to travel from any section to the center of the city without change of cars, but also to enable them to travel from any section to either one of several sections by a through route. One can thus go from *A* to either *E, K* or *C;* from *B* to *G, H* or *K;* from *C* to *F* or *K,* etc., the letters representing prominent points or districts.

As a result of this multiplication of routes, the number of cars in the sections *AP*, *BQ*, *MNF*, etc. is entirely out of proportion to the traffic so that there is a waste of men and fuel.

In putting a system of this sort on a basis of wartime economy, a number of alternatives would, of course, be possible and a study of the conditions would be necessary to tell just which of them would be best. One of these alternatives which should serve to illustrate the general principle involved is shown in Fig. 3. With this arrangement, there is only one through route from each terminal and through any section (except the section *PIJL*, which is the main business district and a short section near the point *K*, but inspection of this diagram will show that it is possible to reach almost any section of the city from any other section with a single transfer. In some cases, however, it would be shorter to make two transfers.

With such an arrangement as shown in Fig. 3, the number of cars on any line can be adjusted to the needs of the traffic much more readily and the cars thus used

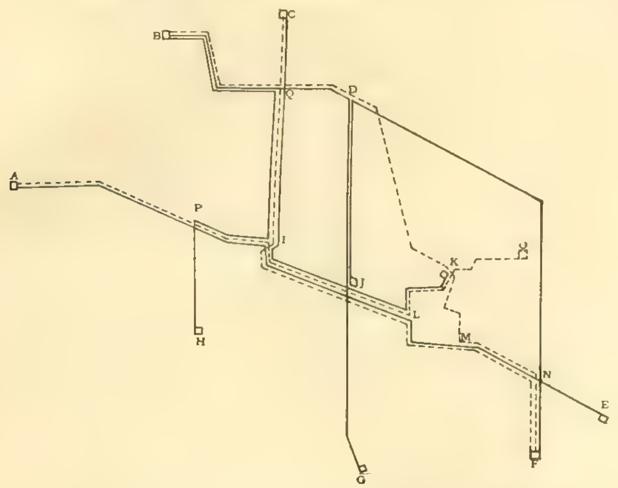

FIG. 2—TYPICAL EXAMPLE OF OVERLAPPING ROUTES

much more efficiently than on the basis shown by Fig. 2. A smaller number of cars, a lesser amount of fuel and fewer men should thus suffice to give the necessary service. There would be only six routes instead of eight also, and in all places except the district *PIJL* and a short section in the neighborhood of *K*, a prospective passenger would take the first car which came along and the system would be simpler and easier for the public to understand and to use.

TRAIN OPERATION

In addition to the direct economies which can sometimes be effected by eliminating overlapping routes, as in the above two cases, the change will often permit an important indirect saving by permitting the operation of two-car trains on an all-day basis instead of single cars, in cases where otherwise this would not be justified. Referring again to Fig. 2, the normal mid-day schedule calls for four minute headway (15 cars per hour) on the line *CQIJLK* and six minute headway (10 cars per hour) on the line *CQIJLF*. There is also a 12 minute headway five cars per hour) on the line *BQIPH*. This gives 30 cars per hour or an average headway of two minutes on the section *QI*. Even with these cars divided into three routes as they are, it would almost seem desirable to operate the first two classes as two-car trains at double their present headway instead of as single cars. However, with this section operated as a single route, it would obviously be desirable to run the cars in trains at four minute headway, rather than singly at two minute headway, for the sake of the economies effected.

The grouping of the cars into trains in this way would reduce the number of men required to three for every two cars, instead of four at present, so that even with the old arrangement of 30 cars per hour, 25 percent less men would suffice. With the cars grouped in units of two, there would be only half as many moving trains as before and hence, less congestion on the streets. Probably, however, with the routes consolidated as in Fig. 3, a two-car train every five or six minutes, giving 24 or 20 cars per hour, instead of 30,

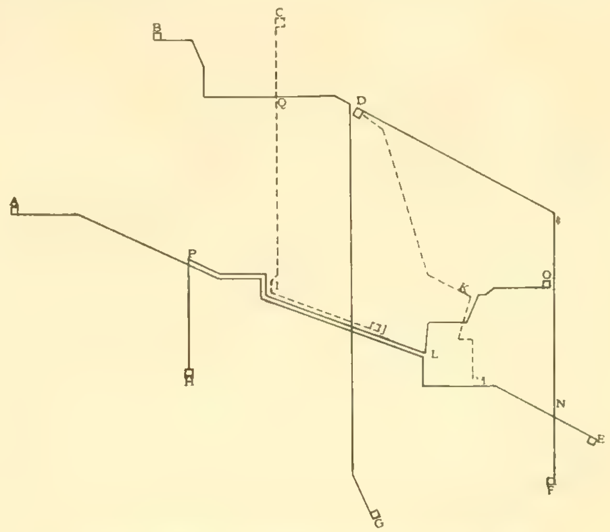

FIG. 3—EXAMPLE SHOWN IN FIG. 2 SIMPLIFIED

would be ample and on the latter basis, there would be a reduction of 50 percent in men, as well as a considerable saving in fuel and equipment.

On the particular line on which the above example is based, this saving of 50 percent in man-power would probably mean the release of at least 50 men and by applying the same principles to other sections of the system, this number could be materially increased. Inasmuch as shortage of labor is one of the greatest difficulties with which we are confronted in general, and from which street railway service in particular is suffering, it will be seen at once that a saving of such a magnitude would be extremely important.

Special Trains for Mills and Factories—Train operation, also, will effect important economies in many cases where large crowds must be handled from mills or factories, especially where these are located several miles from the city as is frequently the case. If 1500 people, for instance, are to be carried away from such a point at closing time, then, allowing 75 people per car 20 cars will be required. If these are operated singly,

40 men will be necessary to run them. If they are operated as two-car trains with one motorman and two conductors, 30 men will be sufficient. If trains of four cars are employed on the same basis, 25 men will do. If the cars are provided with end doors so the conductor can pass from one to the other and if prepayment enclosures are used at the factory or if the cars are run through for a considerable distance without stops, one motorman and two conductors could then handle a four-car train and a total of 15 men or less than 40 percent of the number required for single cars, would be ample.

It is obvious that any scheme which will permit 15 men to perform the work of 30 or 40 men is of vital importance in these war times and should certainly be applied where conditions will permit. Such economy is particularly important in providing transportation to mills and factories, since such service is usually required only in the morning and evening and if a large

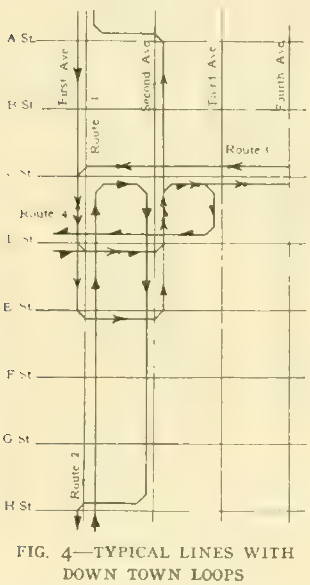

FIG. 4—TYPICAL LINES WITH DOWN TOWN LOOPS

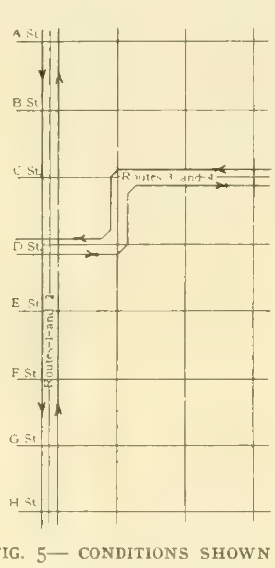

FIG. 5— CONDITIONS SHOWN IN FIG. 2 SIMPLIFIED

number of extra men are necessary at these times only, it is difficult to employ them efficiently during the reminder of a working day.

Limited and Local Trains—In operating trains of three or four cars, the use of limited and local trains can sometimes be employed to advantage. It is particularly desirable that long trains should make as few stops between terminals as possible. Where the majority of passengers wish to travel the full distance between terminals but where there are a few for intermediate points, it may be desirable to operate most of the trains as specials or expresses with one out of every four or five as a local.

One line on which such an arrangement could have been employed to considerable advantage was that running to a certain park, 12 miles from the edge of a city. On Sundays the railway company frequently ran two-car trains to this park, carrying maximum standing loads, at intervals of four minutes. A typical one of these trains on which observations were taken made 18 stops at intermediate local stations between the city limits and the park, at which stops the total number of passengers getting on or off was only 30 or about one sixth of the number on the train, while the remaining five sixths made a through trip. Under these circumstances, it would seem that, at least in war times, it would have been much better to have operated most of the trains on a no-stop through schedule for the benefit of the great majority of people who wished to go to the park, carrying the smaller number for intermediate points on local trains at suitable intervals instead of having all trains stop at local stations. This would have permitted the through trains to make the run in about 33 minutes, instead of 40, and would have effected material savings in men, power and equipment.

THROUGH ROUTES

Fig. 4, indicates the conditions which are found in the business districts of a certain city except that only four different routes are indicated, while actually there are 20. Each line starts from an outlying section, runs to the business district, turns on a loop and returns. Even with only the four routes, it will be seen that the lines cross and recross each other a number of times so that the congestion in the rush hour can well be imagined. This condition is not unusual but is practically duplicated in other cities.

It happens that in this city, the headways and general conditions on routes *1* and *2* are much the same so that it would be a simple matter, instead of operating these lines separately and turning each on a loop as shown to consolidate them and run the cars through from the east side of the city to the west and vice versa. A similar consolidation could also be made of the north and south lines, routes *3* and *4*. If these consolidations were made, the operation of the cars should then be as indicated in Fig. 5, and by comparing this with Fig. 4, its advantages will be obvious.

Considering route *1*, it will be seen that a car in passing around the loop from First Avenue and *A* Street to *E* Street and return must cover 10 blocks. In the same way, a car of route *2*, in passing around its loop, must traverse 12 blocks, making a total of 22 blocks each time a car enters and leaves the business district on these two routes. With the lines consolidated as in Fig. 5, exactly the same result is accomplished by running one car along First Avenue from *A* to H Street and another in the opposite direction from *H* to *A* Street. This, however, requires the covering of only 7 blocks by each car or 14 in all, thus saving 8 blocks of probably 450 feet each, or more than two thirds of a car-mile for each round trip, as well as cutting out the turning of eight corners.

The loops of routes *3* and *4* are shorter and do not overlap as much, but even in the case of these, there is a saving of six blocks, or more than one-half of a carmile per round trip. The speed of the cars in the business district of any city during the rush hours is usually below, rather than above, five miles per hour and, in the case from which the above facts were taken, the cars required about one minute per block. The combination

would thus have saved about eight minutes by the consolidation of routes 1 and 2 and six minutes by the joining of routes *3* and *4*. This would have been enough to save one car from the combination of routes *3* and *4* and probably two cars form that of routes *1* and *2*. In addition to this saving, however, the reduction in time would have made the service more convenient, while the reduction in congestion would have made it more reliable.

TIME TABLES VERSUS CLOSE HEADWAYS

One of the fundamental theories on which the electric railways of most cities have always been operated is that the cars run at such frequent intervals that when one wishes to board a car, he can go at once to the nearest stop without bothering to notice the time. The effort to live up to this idea is often a costly one and leads to the operation of a large excess of seat-miles over passenger-miles on certain parts of routes and at certain times of the day.

On the lines shown by Fig. 6, which may be regarded as a more or less typical example, cars are operated during the mid-day hours from *A* to *B* at six minute headway (10 cars per hour and from *C* to *D* at four minute headway (15 cars per hour). Below the point *E*, where there is a cross-over, the cars are well filled even during the non-rush hours, but between *A* and *E* and *C* and *E*, many of them run with a half-dozen passengers or less.

It would seem that in applying war-time economies to a case of this kind, the cars which now run from *C* to *D* might be run instead from *E* to *D*, thus saving 2.5 miles per car of each round trip and that one-half of the cars which now run from *A* to *B* might also turn back at *E*, thus saving 3.75 miles per round trip for each car thus turned. On a basis of the headways indicated above, this would save 56.25 car-miles per hour or if it were effective for 10 hours per day, over 200 000 car-miles per year. Even if only one-half as many cars as have been considered above were operated on this line, there would still have been a saving of over 100 000 car-miles per year, which would be well worth while on any system.

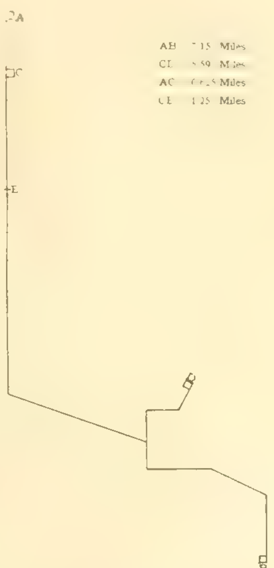

FIG. 6— CONDITIONS UNDER WHICH SHORT RUNS ARE BENEFICIAL

One of the first things which suggests itself when an electric railway company is obliged to economize is lengthening the headways and thus operating fewer cars. Unfortunately, however, where people have been educated to catch cars by going to the corner and waiting, increasing the headway leads to complaints and often to considerable decreases in revenue, so that unless other steps are taken, economies of this sort can easily be carried too far. If the people were educated to catch cars by schedule, however, and given the necessary information to enable them to do this, equally convenient service could then be given with longer headways and economies effected without the above objections. This is clearly indicated by a personal experience.

A short time ago, I wanted to travel over a certain car line. I knew, in a general way, that the cars were supposed to run every 15 minutes. As the point at which I could most conveniently board the car was a prominent one, I thought the car might perhaps be due there exactly on the quarter hour, so I went a minute or two before quarter of two. The car did not appear for some little time and when it did arrive, I noted it was 2:53. I judged, therefore, that instead of being due on the quarter hour, the cars were due eight minutes after. Two days later, I again wanted to take this car. I was able to start a little earlier this time and, remembering my previous experience, I planned to be at the corner at 1:23, thinking I would thus avoid waiting. Once again, however, I was mistaken for this time the car came exactly at 1:30 and I am still in the dark as to which of the two cars was late, or what time they were due. When I again use this line, therefore, I will have to figure on waiting at least 7 or 8 minutes, as before, or possibly 13 or 14.

It will be obvious to anyone who stops to analyze the situation that on account of this factor of ignorance, cars must be run much closer together to afford a given amount of convenience to passengers than would be the case if the schedules were definitely announced and maintained. In the case I have cited, for instance, the service would have been much more satisfactory to me if the cars had run every 20 or even 30 minutes instead of every 15 minutes, provided the schedule had been definitely announced, instead of being concealed.

Judging other people by myself, this same principle applies also to much shorter headways. I would much prefer, for instance, to be served by a line operating at 12 or 15 minutes headway by definite time table, than by one operating at 10 minutes headway on the hit or miss basis, or by one giving 10 minute headway by regular schedule, rather than 7.5 minute headway without.

I firmly believe, therefore, that if this idea is properly made use of, war-time economies can be effected in many cases by increasing the headway with an increase, rather than a decrease in the convenience afforded, and hence with an improvement, rather than a falling off, in financial returns.

COASTING

A motorman, properly trained in operating electric cars, can maintain his schedule with a much lower consumption of power than one who has not been instructed in such matters and who, therefore, pays no attention to the principles of economy. The reduction in the fuel required for operating a given railway which can be brought about by more skillful handling of the cars is often an important item. To realize on this pos-

sibility, however, usually requires greater and more continued effort than for any of the other plans previously suggested. On the other hand, this is a matter in which the public is in no way concerned, so there is no question of authority or jurisdiction.

An electric car rolls so easily that when it has once been started on any particular run, the power may be cut off and even on slight up grades, if the brakes are not applied, it will continue to move for a considerable distance with very little loss in speed. If proper advantage is taken of this fact, power need be applied only to bring the car up to the necessary speed. It can then be allowed to coast, or run by itself until it is time to apply the brakes. It is obvious that if power is kept on too long and the car is given too much of a start, the brakes must be applied to check it sooner than would otherwise be necessary. Economical operation consists in avoiding this and in applying just the right amount of power at each start to take the car at the desired speed to the next stop.

It is just as easy to handle a car the right way as the wrong way—in fact it lends interest to the work—and if a man is properly instructed in the beginning, there is no reason he should not continue on the same basis. The difficulty is, however, that many instructors, themselves, do not understand the importance of the matter or how to present it to their pupils, and they are frequently satisfied when a recruit is able to get his car over the road on time and without accident, regardless of the amount of power consumed in the process.

There are various devices on the market to assist, by giving a record of the power used, the time of coasting, the time power is on, etc. in securing the saving of power which comes from proper handling of the cars. These devices are often of considerable benefit by furnishing a tangible record of the performance of a man and thus enabling him to see the results of his efforts, or by showing the instructor where *his* services are most needed. They do not, however, obviate the necessity for proper teaching in the beginning and a continued effort to keep up an interest. In endeavoring to save, as a means of meeting war-time conditions, the economy in power and fuel which can be effected on many railways by better handling of the cars should not be overlooked. While the installation of any of the various devices on the cars to indicate the results obtained will undoubtedly be a help, the lack of these should not be considered as a reason for delaying, or neglecting this important matter.

REDUCTION IN HEATING

It is often suggested in the interests of economy in power and fuel that the heating of the cars be reduced during the winter, particularly in the rush hours. The amount and the percentage of power and fuel used for the heating of cars varies widely, of course, with the size and kind, as well as with the climatic conditions. In the case of one city for which the information is at hand, approximately 4500 tons of coal, out of the total amount of 79 000 tons which was burned, was required to furnish heat in the cars. This is 5.7 percent. It was estimated that about one third of the 4500 tons, or 1500 tons (1.9 percent of the total burned) was required for heat during the rush hours. It is quite likely that in a more northerly city, this proportion would have been increased, possibly by as much as 50 percent.

There are undoubtedly many cases where cars are heated unnecessarily at times and in the interest of economy, as well as health, it is desirable that this should be avoided. The cutting off of heat to a greater extent than this, however, is rather a mistake and should not be resorted to until all other reasonable economies have been put into effect. When discomfort, or even suffering, is really necessary in the interests of the war, all of us are willing to endure them cheerfully. If we feel, however, that we are subjected to them unnecessarily, while conspicuous waste is allowed to go unchecked in other quarters, it not only arouses our antagonism, but weakens our faith in the efficiency of government officials. Asking us to ride in cold cars therefore, to save fuel, while these same cars waste several times the amount thus saved by making unnecessary stops, or by inefficient routing, etc., is one of the worst of bad policies. There is room in many cities to effect economy by intelligent regulation of heat to prevent unnecessary temperatures; it should not be carried to the point of operating unpleasantly cold cars, however, at least until obvious economies in other directions have first been arranged for. Consistency is always desirable and in no case is it more important, or is the lack of it likely to do more actual harm to the cause, than in endeavoring to effect war time economies.

NATIONAL DIRECTION NEEDED

The great difficulty with the above program of economies, however, is the lack of machinery for carrying it into effect. The officials of the railway companies in the various cities are in most cases entirely familiar with the principles involved, and with the economies which can be effected. On account of franchise requirements, public feeling or agreements with employes, however, they are powerless to carry them out. The public and the employes on their part are willing to agree cheerfully to any changes which may be necessary for the successful carrying on of the war, but unfortunately, they mistrust the railway company to such an extent that they are not willing to accept its statements alone as to the necessity of modifying previous practices. The State Public Service Commissions, in many cases would seem to afford unprejudiced bodies for deciding such questions. These commissions however, have no direct connection with the National Government, and hence, lack the information to enable them to speak with authority, as to war necessities.

If some national body, such as a division of the War Industries Board were appointed to investigate these matters in the various cases, and suggest specific measures to the railways, and the communities concerned, we believe that all parties would cheerfully co-

operate, and that any rulings such a body would make would be quickly carried out. The electric railway industry seems to offer a considerable field for important war economies, not only along the lines mentioned, but in other ways, and in order that these may be put into effect, it is to be hoped that some competent body of this sort will be created for this purpose.

A similar procedure in the central station field was adopted some time ago, but not soon enough to prevent a serious power shortage in various parts of the country. In the interests of conserving the resources of the electric railways for the nation, and maintaining proper service in the various communities, and of doing this with reasonable economy in men, equipment, and fuel, it is important that some competent national authority be established for the task.

War Time Economies for Electric Railways

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FOR nearly a century steam has moved our freight; more recently gasoline has been hauling many thousands of tons of freight in the direction of the battlefields of France. The motor truck is doing wonders in the army transport service, but it must not be considered as a cure-all for transportation. The electric railways are able to haul millions of tons of freight on thousands of miles of rails over which now hardly moves one car per hour.

The Chamber of Commerce of the United States fully realizes the importance of the electric railway as a valuable utility and has asked authorities to give prompt and sympathetic hearing to utility petitions for assistance and relief due to the unusual financial conditions. Increased rates are of vital importance to the utilities, but even more important to the government is the development of electric railway freight haulage.

The spirit of the age is conservation. The prodigal use of man-power cannot be permitted to continue. Millions of tons of freight can be moved by the electric lines with only a slight increase in men, as compared with highway transportation. The handling of 500 tons of freight by motor truck would require at least 100 men driving 100 five-ton units; but by electric railway it would require three or four men, and this same train crew could easily handle four times as much freight. The electric railway requires but one man for every thirty to handle the same tonnage by motor truck, not counting the extra men needed to maintain and repair the highways. The investment in rolling stock alone, to haul 500 tons of freight is easily 1 to 10 in favor of the electric railway, including the electric locomotive.

Inherent operating conditions on electric railways permit the realization of potential possibilities that are of great significance in this day of car shortage. One electric freight trailer car in service is equivalent to five steam road freight cars, and one electric motor car, which may haul several trailers, to three steam freight cars. This is conclusive evidence of the high load factor or efficient utilization of freight rolling stock possible on electric railway systems.

It is unfortunate that an electric railway investment of nearly six billion dollars, representing a mileage equivalent to practically one-seventh of the steam railroads of this country, many miles of which is available for freight, should be used to but 50 percent of its earning power. In many localities shippers need the use of this valuable carrier. It should be developed; it should be fostered and released from some of the restrictions that prevent full use of its facilities.

Mr. P. H. Gadsden, resident member of the American Electric Railway War Board, and president of the Charleston Consolidated Railway & Lighting Company, Charleston, S. C., recently stated that the possibilities of electric freight haulage have hardly been touched and the effort to transport more freight is a national duty. A prominent manufacturer recently told the Transportation Board of the Cleveland Chamber of Commerce that the same effort applied to secure local shipments via the electric railways would be of greater benefit to the country than if handled by the motor trucks. Further, that the real solution in territories served by electric railways lies in the utilization of their service, as the efficiency of the electric road undoubtedly can be made greater than is possible for any system of highway transportation for distances exceeding 20 miles. The science of road building has not produced roads that stand up under the heavy motor truck. Why experiment, when the maintenance of electric roads can be figured accurately?

Restrictions that are now preventing, in many cases, electric railways from hauling freight cars through streets are cheating the nation out of one more effective weapon against Kaiserism. There are too many of these heritages of pioneer railroad days. Money spent to date by many electric lines for paving alone would have purchased right-of-ways so that electric freight haulage could have developed unhampered.

The actual everyday ways of using the electric railway to move more freight and help win the war are humanly interesting. Long before the war the electric railway had shown its ability as a freight carrier and valuable public servant. For years the railroads of Iowa have been hauling the grain and stock from our prairies. Notably among these are the Fort Dodge,

Des Moines and Southern Railroad, Interurban Railway of Des Moines, and the Waterloo, Cedar Falls & Northern Railway. Each of these lines is the equivalent of a steam railroad with a trolley wire over it.

The Waterloo, Cedar Falls & Northern Railway is the pioneer electric line to arrange with the steam railroads for the interchange of freight. As a result, more than 70 per cent of the switching from steam roads entering Waterloo with its 155 factories is performed by this line. Similarly, several steam trunk lines entering Cedar Rapids are fed by the electric line since it serves a northern territory that does not enjoy adequate steam service.

In the Central States, where the electric railway has long been considered as one of the most important factors in the economic development of communities, the electric lines are not only hauling passengers, but are carrying all classes of freight commodities. Indianapolis, the interurban center of the country, now has freight handling facilities completed and under construction that would do justice to many a steam road freight terminal. One item of great significance, when considering the electric line as a factor in relieving freight congestion and alleviating public suffering, is of timely interest. Last winter, due to car shortage on steam lines, it was impossible for farmers to secure cars for hauling their hogs and cattle to the Indianapolis market. The Food Administration appealed to the electric lines and during the winter months over 1000 carloads of hogs were brought to this market. The usual procedure was as follows:—

A day or two in advance the farmer notified the interurban, and at a specified hour on a certain day the electric freight train of two to six cars was waiting for him. Two or three hours later the shipment was at the stock yards, and the farmer with his check, in another two or three hours, was on his way home via the "electric." Hogs generally lost about five pounds each in shipment by steam, but the new way eliminates this loss on account of the short time in transit, which practically balances the freight charges; hence, the farmer figures free transportation. Handling stock is the least desirable freight, but illustrates that electric lines can perform valuable service. Last winter, many of the electric railways were the only transportation agencies moving a wheel during and after a severe storm, including steam trunk and motor truck lines.

The experience of another line is significant. The Chicago, North Shore & Milwaukee Electric Railroad, which skirts the western shores of Lake Michigan between Chicago and Milwaukee, is in an excellent position to serve the numerous fast-growing industries located along its lines. The shippers of this territory already recognize the great value of the reliable service rendered by the line. The traffic has grown so fast that even with the erection of new freight houses many of these are not large enough to take care of the ever-increasing quantities of freight offered for transit.

FIG. 1—HEAVY ELECTRIC FREIGHT TRAIN ON THE PIEDMONT AND NORTHERN LINES

Handling standard steam railroad rolling stock and giving interchange service. Sixty percent of the income of this line is derived from freight operation on its nearly 300 miles of track.

Great relief is possible for freight congestion to all points on the "North Shore" route between Chicago and Milwaukee, if the Chicago city council would approve the plans for handling freight over the elevated and surface lines during the night. With the extension of freight hauling in the Chicago district, this electric line would not be restricted to local freight, but could interchange traffic with other lines radiating from Chicago. This line not only took care of passengers last winter, but when the steam railroads were tied up, meat, milk and coal were hauled to many storm-seiged towns via the "electric", avoiding what might have been a real famine. Ninety cars of coal were delivered to the Great Lakes Naval Training Station just before one storm broke in all its fury. This timely assistance saved the great training camp with its 20 000 Jackies

from suffering for lack of fuel. The same station was also threatened with a bread famine, but a carload was shipped by the electric line.

The industrial center served by the Detroit United Railway System could be benefitted to a greater degree even than at present from the fast service performed by this line, through closer attention to the proper routing of shipments. In the Detroit territory companies

FIG. 2—EAST SIDE FREIGHT TERMINAL OF THE DETROIT UNITED RAILWAYS

Over 2200 cars are loaded monthly at this terminal. The West Side Terminal of similar capacity is under construction. When this is completed, the two will load approximately 5000 cars per month. These are the largest electric railway freight terminals in the world, but will be equalled by the Indianapolis terminal, which is about one-third completed. This picture also shows a type of interurban freight cars which are used in many parts of the country, being made to conform to the general appearance of the interurban passenger cars both in shape and color, owing to local prejudice. This type of prejudice must be overcome before the country can reap the benefit of electric railway freight haulage in the face of the prodigal waste of man power and destruction of highways by motor trucks.

manufacturing airplane motors have often been obliged to make shipments by express, because of not being able to get them over the steam lines fast enough. As the Detroit United through-freight service reaches two important aviation fields, those at Mt. Clemens, Michigan, and Dayton, Ohio, a very rapid transit is possible, which is less expensive and is practically express type of electric freight operation. Although the steam roads have sidings into the aircraft plants, there is no reason why the electric cars of this system could not be "set out" at these plants for such shipments, and help speed up aircraft production.

Camp Dodge, Iowa, with accommodations for 25 000 troops, was constructed from material hauled in 10 563 standard steam road cars during seven months over the 12 mile line of the Interurban Railway of Des Moines. This included the transportation of building materials, supplies, food, munitions, cattle and horses. At the time this camp was established it was thought impossible for the electric line to handle all the traffic. However, neither of the two steam lines, the furthest of which was only three miles away, cared to extend their lines into the camp. Hence, all freight had to be interchanged with the electric line. The service has proved satisfactory beyond all expectations.

It is evident that immediate relief can be secured for the steam railroads through assistance from an existing facility which only needs proper fostering to become at once an important factor in our present national emergency and for the future.

In order, therefore, to affect this relief there should be:—

1—Universal interchange of freight rolling stock between steam and electric lines that can handle steam rolling stock, and Federal financial aid to those electric lines which, with this assistance, could carry this additional traffic.

2—Co-ordination of all transportation facilities.

- a—Steam railroads for long hauls.
- b—Electric railways for short hauls, eliminating duplication of passenger and freight service between steam and electric lines.
- c—Motor trucks to serve industrial centers; to be available for unloading freight cars arriving at terminals, thus releasing them for immediate reloading, and to act as feeders to steam and electric lines from districts lacking rail facilities.

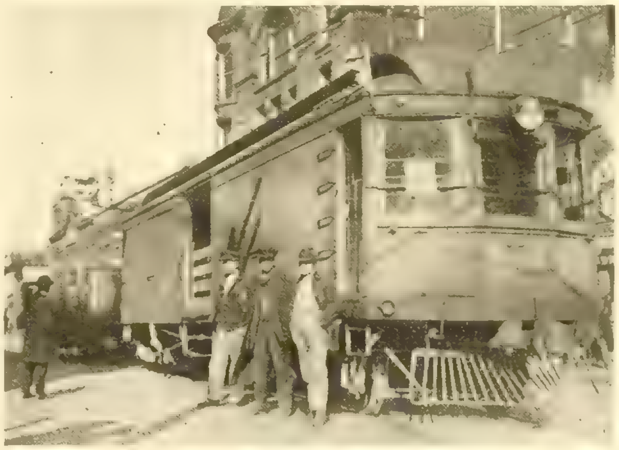


FIG. 3—TYPICAL MARKET TRAIN

Carrying hogs into the Indianapolis Market. Over 1000 carloads of hogs and cattle were handled over the interurban lines entering Indianapolis last winter. Such trains can be hauled through the heart of the city to the abattoirs.

The Success of the Safety Car

G. M. Woods

The general construction and details of equipment of the safety car are well known to practically all men interested in the electric railway industry. The various features that are most important in contributing to the ease of its operation by one man, its appeal to the car riders and the car operators, and the economies of operation which it effects cannot, however, be reviewed too extensively.

THE air brake equipment with its combination of automatic safety devices which have given the safety car its popular name is probably the greatest factor in rendering the car easily and safely operated by one man. The brakes, door and step, and the sanding of the track are all controlled by one brake valve. The arrangement of the valve is such that the step must be up and the door closed before the brakes are released and hence before the car is started. The brakes are applied and the car brought to a stop before the door is opened and the step lowerd. If the operator removes his hand from the electrical controller handle while the car is moving, an emergency application of the brakes is made, the circuit breaker is opened, the track is sanded and the door is opened. A foot valve can be held down by the motorman, and allows him to take his hand from the controller handle in order to make change or issue transfers while the car is in motion. Sand can be applied to the rails by simply pressing down on the brake valve handle.

The use of 24 inch wheels and the low car floor make a motor of small armature diameter essential. The motors differ from older types in the use of higher grade materials and higher armature speeds which in turn necessitate higher pitch gearing than was previously common in railway use. The result is a motor of 25 hp (two of which have ample capacity for the service) weighing complete only 900 pounds. Some of the older motors, rated at 35 hp, formerly used on one-man cars, weighed 2000 pounds.

The controllers most generally used are quite light, one of them weighing but 135 pounds, so that an appreciable saving in both weight and space is effected by their use. These controllers are provided with the dead man's handle feature arranged to operate in conjunction with the air equipment. The grid resistors are also lighter and require less space than those previously used. The weight of the new resistor is about 35 percent that of the old type for equipments of the same capacity.

FIG. 1—SAFETY CAR OF THE TAMPA ELECTRIC COMPANY

A special type of truck is employed on safety cars. It weighs 3300 lbs. complete, has an eight foot wheel base, and usually has 24 inch wheels. Spiral springs are used at the middle of the side bars and at the ends of the quarter elliptic springs. A graduated spring arrangement is employed whereby light loads are carried on lighter springs than the heavy loads. The journal bearings are generally of ball or roller type and the journal boxes are bolted directly to the side bars.

The body of the car is 28 ft. long and eight ft. wide overall and through the use of high-grade materials and careful design weighs only 6700 pounds. The seats are of light construction, rattan being used for the seating material and pressed steel for the pedestals and wall plates. The seats are generally opera style so that closer spacing is possible. Fourteen cross seats are provided and two or four additional seats are available on the rear platform.

A recording fare box with separate hand or foot operated transfer and ticket register is usually a part of the equipment. The foot operated register is desirable because the operator then has both hands free for making change or issuing transfers. A reliable signal system is provided. The location of the signal buttons so that a person of ordinary height must stand up to reach them not only eliminates the unnecessary ringing by children, but also shortens the length of the stops, for after the passenger rises to ring the bell he naturally steps forward to the door and is ready to get off the instant the doors are open. The provision of two trolleys makes it unnecessary for the car operator to leave the car when changing ends. Trolley catchers are provided. So far as the handling of trolleys is concerned the safety car is comparable to the double truck, center entrance car with trolley at the rear of the car.

It is almost universally true that any innovation made by a railway company is met with violent protest from the majority of the patrons of the railway lines. This is especially true when the size of car is to be re-

duced; and when it is to be operated by one man, the patrons at once assume that half the platform men will lose their jobs and this further antagonizes them. The platform men also feel that they will be expected to do the work of two men and they too think that their number will be cut in half. The fact that these opinions are unjustified does not make them any less dangerous, and it is only where they have been disregarded and insufficient steps taken to overcome them that one-man car operation has been unsuccessful. The real merit of safety car operation as now employed in numerous cities and on both light and heavy traffic lines is evidenced by the fact that it is a proven success, where success was not a matter of providing something just as good as the old service, but where it was necessary to establish a service sufficiently more attractive to overcome old prejudices.

One of the most important steps to insure the success of the one-man car operation is to provide a car specially designed for handling by one man. Closing the back door of a heavy old car intended for two-man operation and placing a fare box on the front platform, does not make a one-man car. The duties of the car operator are then practically doubled, no advantage is taken of the possible reduction in operating expenses aside from labor, and the existing antagonism to one-man car operation is increased. On the other hand the adoption of cars possessing the features of the standard safety cars shows that the railway company is sacrificing nothing in safety or comfort of the passengers, and that the manual labor of the operator actually is decreased. In general, a complete line should be changed to safety car operation. If the safety cars are sandwiched in between slower, heavier cars, and cars operated by two men, a certain amount of confusion is caused and the new cars are not given a fair chance to make good. The provision of the safety devices is also a wise step, for in case of accident to a one-man car, the company is in an undesirable position if the car is not equipped with the most up to date apparatus for accident prevention.

The railway company should share the benefits derived by giving the patrons more frequent and faster service. About the same number of seat-miles (at least during rush hours) is usually provided where large double truck cars suitable for the service were used previously, since this plan will ordinarily give sufficiently shorter headways to be attractive. Where the old cars were of small seating capacity, a suitable decrease of headway will give a very desirable increase of seat-mileage. On other lines where cars too large for the service were formerly used (for instance open cars, where the seating capacity is abnormally high) an attractively shorter headway will be sufficient even where the result is decreased seat-mileage. On still other lines of light traffic the same headways may be satisfactory when the company has demonstrated to the public on its heavy traffic lines that it is broad enough to provide the extra service where the traffic demands it. The safety car in itself tends to increase the speed.

The railway company should also share the benefits with the men. The installation of electric track switches wherever feasible is desirable in this connection as well as in providing faster service. The provision of long switch irons, so that the operator can throw switches without leaving the car is also of advantage. The transfer system and operators' daily report should be simplified as much as possible to reduce their work along these lines. Finally they should receive a higher rate of pay than the men on two-man cars.

The next step in the introduction of safety car operation is for the railway company to thoroughly educate the public regarding the new service. Emphasis should be placed on the points that appeal to the public, such as more frequent service, higher speeds, safety features etc. It is a good plan to let the number of platform men get down pretty low, by means of the usual turnover of labor, just before the safety car operation is started, so that there is no actual reduction at that time. The railway company is in a somewhat better position if it can say that not one man is losing his job on account of the safety car adoption. The method of operating the doors and collecting fares, especially where prepayment cars were not previously used, must be completely described in order to avoid delay during the first few days of operation. This educational work may be carried on through advertisements in the local papers and by descriptive leaflets handed to the passengers on the other cars. The best time to carry on this educational campaign is a few days before safety car operation is begun. If it is started too far ahead there is danger of a great amount of objection building up before the cars have a chance to demonstrate their worth. It is better to run the cars over the streets for a week or more before any publicity work is started. They will attract sufficient attention and a number of stops and starts, opening and closing the door and some emergency stops will do much to overcome adverse criticism. Where it is necessary to obtain the permission of regulatory bodies before the cars are purchased a demonstration with a complete safety car obtained especially for the purpose will usually be much more effective than any verbal description.

The operation of the safety car in actual service is interesting. The passenger waiting for a car is impressed by the quick stop that it makes. The door swings open and one or more passengers alight, and the passenger steps on the car. If he is the only one boarding, the door is closed immediately and the car starts. The passenger drops his fare in the fare box, or if he does not have the exact change the operator usually notches up to full series only and holding his foot on the foot valve has both hands free to make change. If several passengers are boarding the car, those with the exact fare ready often pass the one who has to obtain change. Usually the operator can estimate fairly closely the number of transfers required on any trip and will have them at least partially prepared

before they are asked for by the passenger. If one or two passengers ask for transfers at a certain stop the operator starts the car and issues the transfers while holding his foot on the foot valve. If a number of people are boarding at one time conditions, so far as fare collection is concerned, more nearly approach those on the usual type of prepayment car with both motorman and conductor. Under these conditions, and where a large number of transfers are usually required, the operator frequently saves time by asking those in line how many want transfers.

On the less congested parts of the run, the operator registers the fares. He also relieves the monotony of holding down the controller handle by pressing down on the foot valve, and running with the controller handle up. Since the foot valve requires more effort to hold it in place than the controller handle, nothing is sacrificed in safety by this method of operation. In some cases the operator occupies his chair at all times,

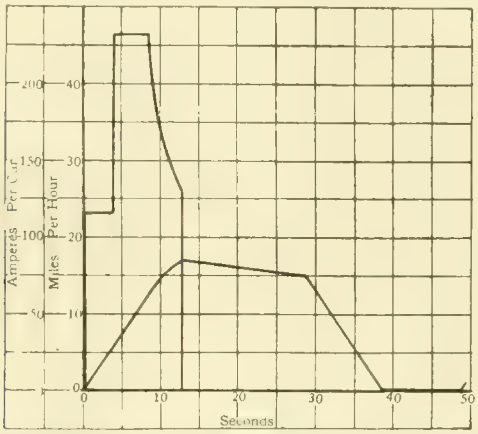


FIG. 2—SPEED TIME AND CURRENT CURVES FOR A STANDARD 48 000 POUND, DOUBLE-TRUCK CAR, EQUIPPED WITH 450 HORSE-POWER MOTORS

Total weight of car with average load—tons	24
Motors—50 hp. Number per car	4
Gear ratio—15:69. Wheel diameter—inches	33
Average voltage at car	500
Substation voltage	650
Acceleration and braking—m.p.h.p.s.	1.5
Train resistance—by Blood's formula, modified	
Grade resistance	0
Stops per mile	8
Length of stop—seconds	10
Schedule speed—m. p. h.	9.23
Kilowatt-hours per car-mile (at substation)	3.17

but in others a separate receptacle is provided for the chair and the operator stands through the congested district.

At railroad crossings where flagmen are employed, the procedure is the same as on two-man cars, a stop generally being made before the car crosses the tracks. Where no flagman is employed, the usual method is for the car to stop, the operator to look both directions for approaching trains, and then to cross the tracks. Where a good view of the railroad tracks cannot otherwise be obtained, the operator leaves the car and walks ahead to the middle of the tracks before running the car across.

At the end of a line where ends of the car are changed the passengers are discharged, and the doors closed. The trolley is raised by reaching out of the window. The operator then carries the fare box and operating handles to the new front end and pulls down the trolley at that end. He then turns the seats and taking his station at the front of the car opens the door for passengers to board. It requires about one minute to change ends, exclusive of the time for passengers leaving and entering the car.

That the public likes safety car service after it is acquainted with it is shown by the fact that in towns where they are used on certain lines the patrons of the other lines ask that the service be extended to the lines on which they normally ride, and where two lines parallel, many living farther from the safety car line will walk the greater distance in order to take advantage of the better service provided. Recently published data show increases in receipts of from 25 to 60 percent on various lines on which safety cars are operated. In some of these cases the riding on other lines in the same cities has increased but to a less extent. Where an in-

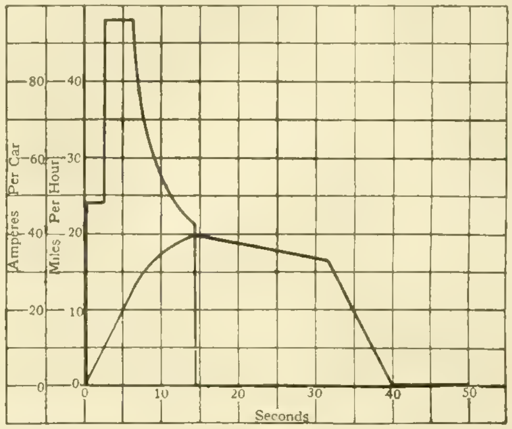


FIG. 3—SPEED-TIME AND CURRENT CURVES FOR A SAFETY CAR WEIGHING 16 000 POUNDS AND EQUIPPED WITH TWO 25 HORSE-POWER MOTORS

Total weight of car with average load-tons	8
Motors—25 hp. Number per car	2
Gear ratio—14:68. Wheel diameter—inches	24
Average voltage at car	560
Substation voltage	650
Acceleration and braking—m. p. h. p. s.	2.0
Train resistance—by Blood's formula, modified	
Grade resistance	0
Stops per mile	6.4
Length of stop—seconds	10
Schedule speed—m. p. h.	11.28
Kilowatt-hours per car-mile (at substation)	1.09

ferior system of fare collection was previously used, a certain percentage increase in receipts is due to all the fares being collected and to the elimination of dishonesty on the part of the platform men. Indications are, however, that the safety car operation alone generally increases the car riding at least 10 to 15 percent.

One of the reasons for the public satisfaction is the shorter headway usually operated. It is axiomatic that more frequent service increases car riding, but unfortunately the cost of operating the older types of cars on shorter headways, eats up the increase in income. The somewhat higher scheduled speeds which are practicable with safety cars are attractive. The passenger not only has a much shorter wait for his car, but when it does come, it takes him to his destination more rapidly. The average speed is higher than that of the

older cars, on account of the higher rates of accelerating and braking and because fewer passengers are carried per car and hence fewer stops are made. The decrease in running time seems really greater than it is. The rapid opening and closing of the door, and the high rates of accelerating and braking, make the passenger feel that the car operator is making every effort to take him where he wants to go just as quickly as possible.

The passengers appreciate the provision made to prevent accidents. They realize that with the door control used and everyone getting on and off the car directly in view of the operator, boarding and alighting accidents are eliminated. The safety of operation is especially noteworthy when compared with the jitney, whose competition the car was designed to meet. Not only is the operation of the safety car inherently free from accident, but there is a responsible concern back of the car to pay for any damage that may be done, instead of an irresponsible jitney driver. By meeting the jitney on its own ground and providing fast, frequent service, the safety car has successfully met jitney competition. Due to the quick "get away" of the car, an automobile will be unable to pass a car making frequent stops for as far as ten squares.

The car is pleasing in appearance both outside and inside. Due to its low construction, it looks longer and much wider than it really is. On the street it looks like a real car in marked contrast to the old types of single truck cars. The interior of the car is well finished, and has an appearance of simplicity and efficiency. The riding qualities of the car due to the scientific design of truck and the use of only cross seats are excellent. In this respect, the car is beyond comparison with the jitney.

The positions as car operators are usually awarded to the platform men on a seniority basis. Even where the men felt before operating the cars that two men would be required, there has been no difficulty in securing safety car operators. In most places there is a waiting list of men that have qualified as operators, but for whom places are not available. The car operator must be mentally alert as his duties are varied. In general, the younger men are quicker in picking up the fine points of safety car operation, and the ex-conductors seem to learn to handle the electrical controller and air more quickly than the ex-motorman learn to handle the fare collection. But old and young, motormen and conductors soon learn to operate the car with equal ease. There has been no trouble in weeding out the men that are temperamentally unfitted for the work.

The duties of the car operator are more complex than those of a motorman or conductor, but they are more interesting. Interesting work is substituted for drudgery. The operator seems to feel a certain amount of pride in his being in sole charge of the car. There is no one else to share the praise for good operation, or the blame for poor. The ex-motormen appreciate the saving of time they can make at stops because they do not have to wait for a conductor who is slow in giving them the bell and there are no signals to misunderstand. They also like the coming in direct contact with the passengers. One of the reasons for both former motormen and conductors liking the cars is the fact that they are kept in a more alert state. A day passes far more pleasantly and quickly for the man who is comfortably busy all the time than for one who is busy for 30 seconds out of each minute, and is inactive both physically and mentally the other 30 seconds. Finally the increased pay per hour which is usually granted the car operators and enables them to earn more money in the same number of hours, or substantially the same money in fewer hours, makes them better satisfied and tends to attract a higher grade of men.

TABLE I—SERVICE COMPARISONS

	Old Service	New Service
Weight of car with average load-tons	24	8
Seating capacity	45	30
No. of motors per car	4	2
Horse-power per motor at 600 volts	50	25
Single trip distance-miles	3.46	3.46
Single trip time, including layover-min. (non-rush)	22.5	21
Single trip time, including layover-min. (rush hr.)	24	22
Headway non-rush, 15 hours daily-min.	9	6
Headway rush hour, 4 hours daily-min.	6	4
Number of cars non-rush	5	7
Number of cars rush hour	8	11
Car hours per day	107	149
Car miles per day	970	1455
Seat miles per day	43650	43650
Average number of stops per mile	8	6.4
Average duration of stop-seconds	10	10
Kw-hr. per car mile measured at sub-station	3.17	1.09
Power cost per day at 1c per kw-hr.	$30.75	$15.90
Labor cost per day at 70c per car hour	74.90	
Labor cost per day at 38c per car hour		56.60
Car maintenance per day at 1.5c per car mile	14.55	
Car maintenance per day at 0.75c per car mile		10.90
General expenses and maintenance of way	67.90	67.90
Total operating expenses per day	$188.10	$151.30
Total operating expenses per year	$68700	$55200
Saving in operating expenses per year		$13500
Saving in operating expenses in percent		19.7
Cost of 12 new cars at $6500 each		$78000
Return on investment percent		17.3

The increase in schedule speed that is feasible and the increased receipts and decreased operating expense have all been demonstrated many times in actual service. Typical speed time and current curves are shown in Fig. 1 for a double truck car with a seating capacity of 45 and weighing 48 000 lbs. complete with an average load of 30 passengers. The motor equipment is assumed to be four 50 hp, 600 volt motors. Accelerating and braking rates of 1.5 miles per hour per second are assumed. The average voltage of the car is assumed to be 500 and the bus-bar voltage 650. The stops are taken as eight per mile and of ten seconds average duration. The schedule speed with five percent speed margin is 9.23 miles per hour. During non-rush hours no layover is allowed in Table I, but during rush hours the layover is 1.5 minutes.

Typical speed time and current curves are shown in Fig. 2 for the safety car seating 30 passengers, and weighing 16 000 pounds complete with an average load of 20 passengers. Accelerating and braking rates of

2.0 miles per hour per second are assumed. The average voltage at the car with only the safety cars on the line would be approximately 570 volts, but to make allowance for other cars on portions of the line 560 is used. Due to the decrease in passengers per car the number of stops per mile should be decreased to 6.4. There would also be fewer passengers per stop but the duration of stop is left as ten seconds. This is longer than the average stop with safety cars; the average duration of passenger stops is generally more nearly five to seven seconds. The schedule speed with five percent speed margin is 11.28 miles per hour, or 22 percent higher than the old cars. To be conservative however, an actual increase in schedule of 15 percent is allowed in Table I, although the calculated energy consumption is left the same. A layover of 1.5 minutes during the non-rush hours and 2.5 minutes during rush hours is also added. The maintenance of safety cars will be from one third to one half that of the old cars on a car mile basis. In the tabulation one half is used. The maintenance of way will surely be reduced and the general expenses should also decrease, but owing to the lack of definite data on these items, it is difficult to evaluate the saving and no reduction is made in the table. No allowance is made for scrap or second hand value of the old cars replaced. Under present conditions a car that is in even fair condition is salable, and for average cars the investment in the example chosen would probably be reduced one-third with a considerable gain in percent return resulting.

Attention is called to the fact that with 50 percent greater car mileage and correspondingly more cars on the track, the total operating expenses are decreased almost 20 percent, which saving pays 17 percent on the entire cost of the new cars required. It is believed that this estimated saving is lower than will actually be obtained in the majority of cases. When one adds to this saving the increase in receipts that results, he understands why the railway companies now operating safety cars are extending their use as rapidly as possible. Reports from these properties indicate satisfied passengers and platform men, higher earnings, and reduced cost of operation with surprisingly high return on investment. The universal comment is "We only wish we had twice as many of them".

The Application of the Ventilated Railway Motor

S. B. Cooper

THE gradual accumulation of experience in the operation of cars equipped with light weight motors indicates the necessity of a modification in established methods of motor application. The "five cents per pound per year" campaign has resulted in the development of railway equipment which would have been considered beyond the range of possibilities ten years ago, and which must satisfy even the most extreme of the light weight enthusiasts.

As far as the electrical equipment is concerned, the principal reduction in weight has been made by the use of fan ventilation and higher armature speeds; the undesirable effects of higher armature speeds on power consumption have been partially offset by the greater gear reductions made possible by finer pitch gearing. The effects of fan ventilation on the application of the motors, however, have not so far been fully appreciated. There has been a wonderful saving in weight, but certain incidental accompanying changes in characteristics should be given careful consideration in order to avoid trouble from these causes.

The progress that has been made in weight reduction is indicated in Figs. 1 and 2 which show respectively total weight plotted against rated horse-power at 600 volts, and total weight against continuous capacity at 300 volts. A modern ventilated motor of a given horse-power weighs about 85 percent as much as its enclosed predecessor. If the comparison is made on the basis of continuous rating, as in Fig. 2, the new motor weighs from 50 to 70 percent of the old.

The remarkable reduction in weight has been accompanied by changes in the "relative" ratings of the motor, and this fact has not, perhaps, been given as full consideration as it deserves. For instance, the new ventilated motor may have a continuous current rating at 300 volts of 60 percent of its one-hour current rating, where the older enclosed motor had only 44 percent. The old motor had then 36 percent greater one-hour capacity than the new motor, on the basis of the same continuous capacity. The significance of this lies in the fact that the one-hour rating is at least a rough indication of the thermal capacity or heat-storing ability of a motor. Short steep grades or short heavy rush hour overloads, which may not have been considered in the original choice of the equipment on a continuous capacity basis, would not have the marked effect on the temperature of the heavier motor that it would on the ventilated motor, which has a smaller amount of material and, therefore, a smaller heat-storage capacity.

For instance, assume a car equipped with enclosed motors of a given continuous capacity operating on a city line. During the afternoon, the ordinary service probably works the motor practically up to its full normal working temperature. A heavy rush hour load with its accompanying increased frequency of stops causes a certain increase in motor heating; with the comparatively large amount of material in the older enclosed motors, with their lower armature speeds and less effective ventilation, this increased motor heating resulted in a comparatively slow temperature increase,

so that at the end of the one-way, heavy trip, lasting perhaps 40 or 45 minutes, the motors were still within safe temperature limits. The return trip, usually with less than the average load and frequency of stops, gave the motors opportunity to cool off again before starting a second rush trip.

With the ventilated motor of the same continuous rating however, the smaller masses of material offer smaller heat storage capacity, and its temperature will, therefore, respond much more quickly to fluctuations in load. Recent tests with thermocouples placed in motors so that continuous records of motor temperatures could be obtained show this effect very clearly, and indicate the necessity of a more liberal margin for rush hour conditions than has been standard practice for enclosed motors.

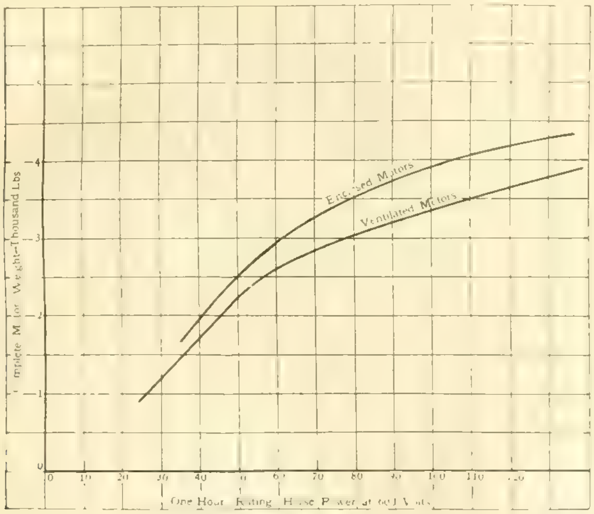
It is more or less commonly accepted that the maximum working current to be allowed in a railway motor should not be greater than twice its one-hour rating. With the maximum gear reduction in each case, the tractive effort exerted at twice the one-hour current per ampere of continuous capacity will average approximately 94 lbs. with non-ventilated motors, compared with 63 lbs. with the ventilated type. This means then that a given car in a service requiring a continuous capacity of four amperes per ton, if equipped with enclosed motors would have available maximum tractive effort capacity of 376 lbs. per ton as against 252 lbs. per ton with the ventilated equipment. In other words, the car with enclosed motors would be able to start with an acceleration of one mile per hour per second on a 12.5 percent grade without exceeding twice the one-hour motor current, while ventilated motors would be worked to this limit on a grade of 6.6 percent. These figures are, of course, illustrative only and simply show the comparative values to be expected.

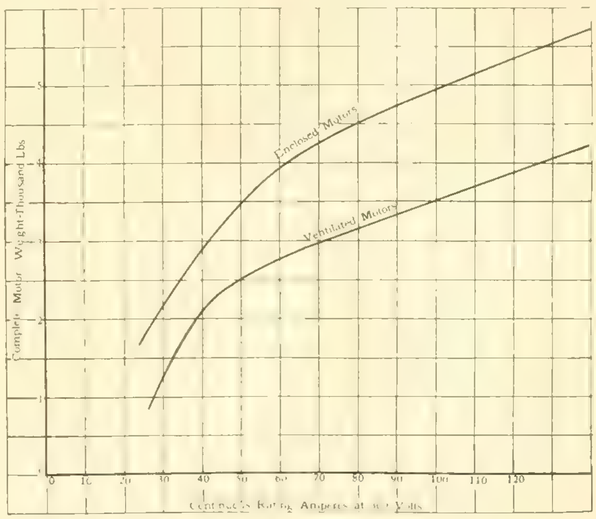
The reduced weight has naturally led to smaller mechanical dimensions, with a corresponding decrease in ruggedness against the exceedingly severe vibration and shocks that are inevitable in electric railway service, not to mention the severe overload conditions frequently imposed on railway motors.

Short steep grades, rush hour loads, operation with a motor or pair of motors cut out, pushing dead cars, bucking snow, etc., all call for loads on the equipment far beyond those on which their application is usually based. These overloads are especially severe on motors having high continuous rating in proportion to their thermal capacity, mechanical strength and commutating capacity, and will undoubtedly be reflected in the maintenance account in the long run. It is difficult to assign definite values to reliability of service, but it appears perfectly evident that a conservatively applied equipment with a high record of reliability, comfortable margin in capacity and low maintenance cost is worth a good deal as an investment, especially when it is considered that the extra first cost of this margin is comparatively small.

A typical case recently worked out showed that by increasing the first cost of an equipment $500 per car, an estimated saving in maintenance and depreciation of $.02 per car mile or $80 per car year could be realized. This, of course, is by far the least important part of the benefits to be derived from the greater margin in the capacity of the equipment. The improved reliability of service and greater freedom from pull-ins and tie-ups, with the resultant favorable effect on the mental attitude of the public, cannot be evaluated in dollars but are nevertheless vitally important factors in the operation of a property. Furthermore, a manager whose time is largely occupied with watching his equipment and providing against emergencies due to its failures naturally cannot be as free as he should be for the consideration of the broader problems that require his attention, particularly in these times of high expenses and comparatively low income.

The ventilated railway motor has undoubtedly come into the field to stay, and it is a splendid piece of apparatus, whose introduction has accomplished wonders in reduction of weight and increase in motor capacity. We simply wish to point out that the ventilated motor differs somewhat in certain characteristics, thermal and overload capacities particularly, from its non-ventilated predecessor and, therefore, calls for closer attention to these factors in its application.





FIGS. 1 AND 2—COMPARATIVE WEIGHTS OF ENCLOSED AND VENTILATED MOTORS

Operation of Ventilated Motors under Snow Conditions

R. E. Ferris

THE winter of 1917-18 was exceptionally severe on railway motors on account of the frequent heavy snows. All types of motors were affected to a greater or less extent. However, the quite radical departures in the ventilating system of the modern motor from the construction of the old semi-enclosed types had a tendency to concentrate attention on the later types of motors, although on the average they were giving no more trouble than the older types and until last winter had given even less.

The severe service conditions during the winter of 1917-18 were also accentuated by the bad labor situation. The following quotation from the report of an investigator indicates conditions which were typical of those in many localities. "The covers on the ventilated motors were in bad shape. Many of the commutator covers were missing, having been forced off by the brake rigging. In one instance canvas was found over the commutator opening, but in the majority of cases the opening was uncovered. The inlet covers were caved in, in some instances, and in one case a cover was found hanging down at an angle of about 45 degrees, acting as a scoop for the snow. The outlet covers were broken and in some cases entire sections were missing. Many of the motors showed that an excess of oil had been used. The oil was running down the outside of the housings and also down on the inside. The covers on the oil well opening on many of the motors examined were found open, time not being taken to put them down after oiling."

A large number of points enter into an analysis of the operation of railway motors under snow conditions, which may be roughly classified as follows:—

CLASSES OF SNOW

As every railway operator knows, snow falls under a variety of conditions. First, the snow may be light and flaky, falling with very little wind, or this may be accompanied by a high wind. Another form of snow is wet and heavy, with or without wind. Again the snow may be fine and hard, this type of snow being generally accompanied with more or less wind. Motors which operate with absolutely no trouble under certain classes and conditions of snow may give a large amount of trouble under some other condition, so to state that the motor will or will not operate under snow conditions is in either case a rather broad statement.

The Manner in Which Snow Enters Motors depends largely upon the type of snow. For instance, if the snow is light and fine and is more or less suspended in the air, it may be drawn into the motor by the action of the ventilating fan. If there is a high wind and the car is running through open country over which the snow is more or less drifted, the snow may be forced in by the action of the wind or the operation of the car through drifts. For example, the writer has observed cars operating through open country, at high speed, on which the snow was jammed up over the trucks and motors in such a way as actually to force snow into the motors providing there was any opening at all, either outlet or inlet. Under such conditions as these, it seems that the only possible solution is to close the motors up absolutely tight as the entrance of snow in this case is due to a high external pressure and not to fan action. Also with this snow piled up over the trucks and motors, if the temperature of the motor is sufficiently high to cause the snow next the case to melt, water will enter the motor if there is the least possible chance. Under conditions such as these, i. e., with snow packed on top of motor and truck, it is practically impossible to have an inlet opening on top of the motor and less snow will be admitted with the openings at the bottom. On the other hand, in city service it has been found that the bottom intake covers are greater offenders as regards the entrance of snow than are top intake covers. This is largely due to the smaller clearances, and to the fact that the snow may be piled in such a way that the motor acts as a plow pushing the snow into the bottom intake.

EFFECT OF SNOW

Under practically all conditions of operation the snow which enters the motor is turned to water, with which the field coils and armature windings are more or less soaked, thus giving a chance for leakage current, and finally for a ground or short-circuit. At times, however, the conditions are such that the snow first partially melts and is then frozen in the form of ice. This is especially the case if the motor has been operating fairly warm and is then stopped for any cause, such as stalling in a snow drift, or because the power goes off. In this case the whole motor may be frozen into a solid mass of ice, including brush holders and commutators, and when an attempt is made to start again, more or less damage is done. A motor which has had ice frozen on the commutator is very easily detected, because of the peculiar burning of the commutator.

CLASSES OF SERVICE

In city service, in general, the tracks are fairly well cleared of snow, and what snow does enter, is more liable to come from the bottom intake covers. However, under certain conditions of snow it may enter at the top commutator covers also.

In interurban service on the other hand, tracks will not be cleared, and the car may be bucking snow drifts to a greater or less extent. It is readily evident therefore, that motors which operate satisfactorily in one class of service may not do so in the other with the same arrangement of covers.

WATER AND WHEEL WASH

In some cases, especially in city service, the car may be operated over tracks where there is excess of water, and the motors subjected not only to direct con-

tact with the water, but also to wheel wash. This again introduces a new condition as regards the entrance of moisture into the motor, and covers which, in general, prevent the entrance of snow, may not be at all adequate for wheel wash. Tests, however, have been made which indicate that it is possible to arrange covers in such a way as to prevent, to a great extent, the entrance of water due to this cause.

POSSIBILITIES OF BAFFLING SNOW

A large number of schemes have been suggested for baffling the snow and thus preventing its entrance into the motor, but in general it may be stated that these baffling covers merely minimize the entrance of snow. In some cases in interurban service it has been found that with intake openings at the bottom the motors are automatically baffled from the entrance of snow in the following manner: first, a small amount of snow enters, which is turned into water and runs down to the intake opening where it is frozen, thus closing the intake opening until the temperature of motor reaches the point where it is melted.

For bottom covers the best plan seems to be to take the air in through a baffled cover with the outlet

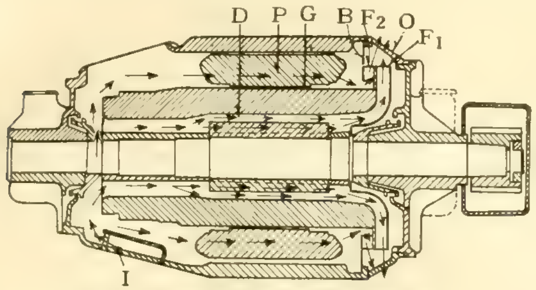


FIG. 1—LOCATION OF BAFFLE PLATES

into the motor towards the commutator end housing. In this way, if the snow is forced in, the opening will soon plug up and prevent further entrance of snow. At the same time with a bottom cover there is less possibility of snow being drawn in by pure fan action. This method of taking air into the motor is shown in Fig. 1.

INFLUENCE OF TEMPERATURE ON OPERATION

If the motor is operated too cold it will not dry itself out, and any moisture which enters may do considerable damage after a certain length of time. In other words, a motor which runs reasonably warm will take care of itself better under snow conditions than one which does not get warm. On the other hand, if a motor is operated at a sufficiently high temperature to dry out and carbonize the insulation, any moisture which enters is immediately soaked up into this dried and charred insulation, and in a short time the motor will be either grounded or short-circuited.

In some cases it has been found desirable to use solid covers during the winter months for two reasons:—first, to keep out the snow; and second, to raise the temperature of the motor during the cold weather sufficiently to keep the insulation dry.

SWEATING MOTORS

Under certain conditions, motors which are brought into the car barn may sweat, in which case, if the insulation is at all dry or open, it will absorb a large amount of moisture and when the motor is placed in service again may ground or short-circuit very quickly. This explains, possibly, the reasons for the grounding or short-circuiting of motors a short time after they have started out on a route.

GENERAL

In general, each individual case should be handled on its own merits. This is because of the variety of service and also the variety of snow conditions which are met in different localities. For example, a certain city and interurban system operating ventilated motors had gone through almost two seasons with absolutely no signs of snow in the ventilated motors, and the operating men were very enthusiastic regarding the operation of the ventilated motors, as they had passed through apparently the most severe snow conditions possible. However, near the end of the second season a light but copious snow fell, this snow being suspended in the air and during this snow storm the motors drew in an excessive amount of snow. In this particular case no damage was done, but it does show the variable conditions—conditions which create a problem whose general solution can be obtained most accurately by engineers who have had a broad experience with a particular line of motors under widely varying conditions. It is therefore, advisable to consult the manufacturer of the motors to obtain suggestions for the best methods of preventing trouble from snow and moisture.

INSURING OF VENTILATED MOTORS

A few particular precautions are, however, generally applicable to all cases. From the foregoing it is very evident that ventilated motors should be capable of withstanding a certain amount of snow, as it seems practically impossible to entirely prevent its entrance. One of the best methods of insuring motors against the absorption of moisture is dipping and baking,* which renders the windings practically waterproof.

Even though the motors are not dipped and baked every year, it is advisable to blow them out well before starting the winter season. The care of covers is also quite essential to the successful operation of the ventilated motors. In some localities and under certain conditions of service it may be absolutely necessary to use solid covers all the way around.

As before stated, it seems to be practically impossible to prevent some moisture from entering motors even with closed covers, unless the covers are gasketed all the way round. This being the case, it is essential that drain holes be provided in the motor to permit the moisture which does get in to drain out rather than stand around the bottom field coil.

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*For descriptions of the process of dipping and baking see "Railway Operating Data" in the JOURNAL for April 1918, p. 137, and for June 1918 p. 240; also articles on this subject by J. V. Dobson in the *Electric Railway Journal* for June 15, 1918; and in the *Street Railway Bulletin* for August, 1918.

Simple Door Signaling and Interlocking Connections

A. H. Candee

The use of safety devices for street railway equipments is rapidly increasing, brought about by a recognition of their economic value. In these days of intensified activity, the class of labor available for the operation of railway cars or trains is fast deteriorating, which adds to the imperative need for simple yet reliable safety devices. The reduction in available man-power is also causing an increase in train operation of city cars, which again adds to the demand for signaling and safety interlocking systems.

Some very interesting developments in door interlocking and signaling systems have been brought about in the past few years, and new systems are continually being brought out to cover new applications. The use of lights in connection with door switches to indicate to the motorman that all doors in the car or train are closed, has become very widespread, and for single cars is fairly well standardized. Systems involving train operation, however, are more complicated and vary widely, especially where the car control is also interlocked through the doors to prevent starting before the doors are closed. It is hoped that both the indicating and the interlocking systems for single cars and for trains will be stabilized in the near future.

The principles of door signaling involve only the establishment of a circuit from the trolley through a resistor, the various door switches and indicating lamps to the ground. It is customary to leave the door to be operated by the motorman out of the signal circuit, as this is under the direct surveillance of the motorman and the car may be gotten under way sooner if started while this door is being closed. One system of door signaling where the lights burn when the doors are open is indicated in Fig. 1. In general, the connections shown by this figure are not the best, as they operate on a negative principle, so that failure of the resistor, door contacts or lamps may give an erroneous indication to the motorman. Fig. 2 indicates the connections for a positive system where the lamps light to indicate that the doors are closed.

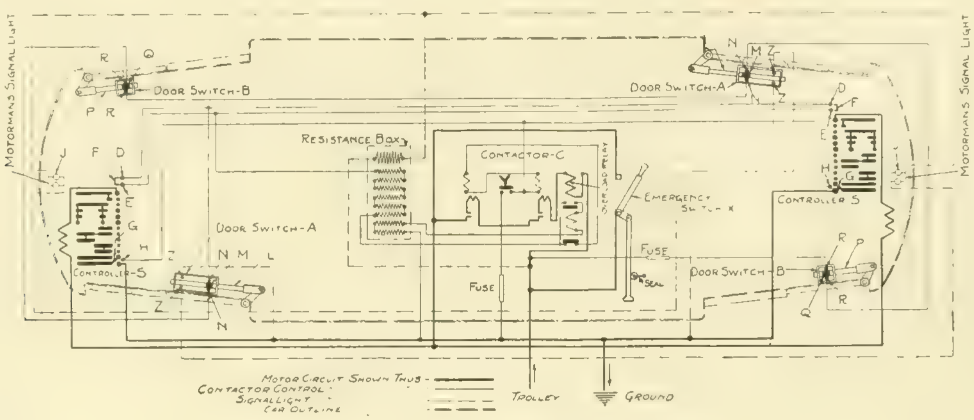


FIG. 1—SAFETY INTERLOCKING DOOR CONTROL
In which lighted lamps indicate an open door.

For trailer operation or for train operation where the car control is not interlocked through the doors, either one of the two systems shown by Figs. 1 and 2, is extended to put all of the door contacts on both cars in series. This may be accomplished in several ways. Fig. 3 shows a simple method for two motor cars, employing one train line wire and three-way switches in each end of the car. The use of such switches, however, may lead to confusion due to the motorman's throwing them to the wrong positions. The most recent systems, therefore, aim to make the proper connections automatically. This is done by passing the door signal circuits through contacts on the controller reverse drum and for train operation, through a double-heading switch which is thrown automatically when the air

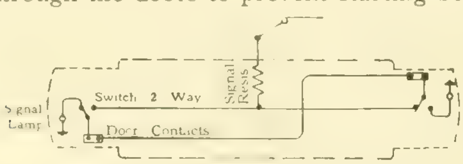


FIG. 2—DOOR CONTROL SYSTEM
In which lighted lamps indicate that the doors are closed.

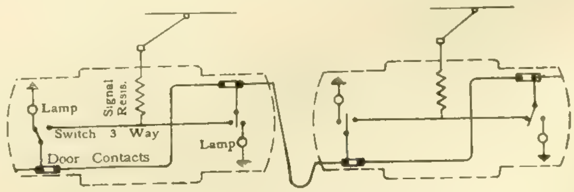


FIG. 3—INTERLOCKING DOOR CONTROL
For multiple unit operation by hand operated switches.

cocks are opened to the air coupling. One of the systems in use is shown schematically in Fig. 4, which shows the circuits for a single car only. Connection to the source of power is made at the rear of the car or train through the rear controller in the neutral position, through the double-heading switch contacts, thence through the door contacts in series to the front controller in the *forward* operative position. It will be noted that if the controller is thrown to the *reverse* position, the signal connections are not made. The general scheme of connections shown by Fig. 4 embodies the essentials which eventually must be included in any standard system.

In order to interlock the control with the doors to prevent accidents due to the car or train starting while loading or unloading, at least one remotely controlled switch is connected in the main motor circuits. Multiple unit control equipments of course, embody the essentials required for this, but *K* controllers must be supplemented by a line switch or other device to accomplish this result. With the addition of such a line

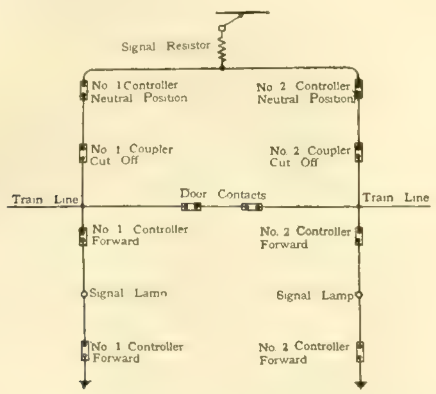


FIG. 4—INTERLOCKING DOOR CONTROL

For multiple unit operation with automatic signal connections.

switch, it is necessary to equip the *K* controller with some other device, such as a slip ring, line switch attachment or ratchet switch and contacts which close the line switch when the controller is in the first position only. Fig. 1 shows a special arrangement of line switch used in connection with a *K* controller in which the line switch is brought in through a contact on the controller in the first position and held in by an interlock on the line switch. The connection of the overload relay, wherein a coil holds the relay in the tripped position has not been generally adopted with door interlocking systems.

One such type of connection for a *K* controller is shown in Fig. 5. The control resistor is energized through the line switch attachment when the controller is thrown on. This energizes the line switch operating circuit at a relatively low potential, the circuit being completed only through the door interlocks, with the controller in its first position. Completion of this circuit brings in the line switch and the line switch interlock completes the circuit to by-pass the contact made on the first controller notch. If the circuit is broken by a door being opened, or in any other way, it is necessary to return the controller to the first notch to resume

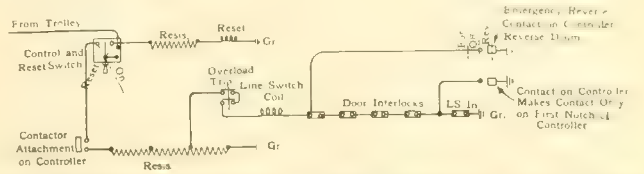


FIG. 5—SCHEMATIC DIAGRAM OF DOOR INTERLOCKS FOR A DRUM CONTROLLER

power. The use of a slip ring or ratchet switch in place of the line switch attachment makes it necessary to return to the *off* position and then back to the first in order to resume power, these devices being arranged so that they open the circuit as soon as the controller handle is moved back a short distance. A somewhat more complicated arrangement is shown in Fig. 6, including a special overload relay similar to that shown in Fig. 1.

K control equipments in general are for single car operation. Multiple unit equipments on the other hand embody train operation which necessitates contacts arranged as shown for door signaling, Figs. 3 and 4. It is customary to energize the control main through the door interlocks in series, feeding from the rear of the train through to the operating controller at the head end. Emergency contacts are usually provided on each master controller to cut out all door interlocks when reversing.

A description of all door interlocking connections now in use is impracticable here on account of the multitude of different types of control with which this interlocking is combined. Some use a battery as a control source, with the controller drum at battery potential or at ground potential. Other master controllers are energized at 600 volts. Still others use 600 volts energy and a lower voltage on separate portions of the master controller. In some cases the door interlocks are in the high-potential circuit, while in special cases they are connected in the ground return circuit or in circuits of intermediate potential. In each case, however, the gen-

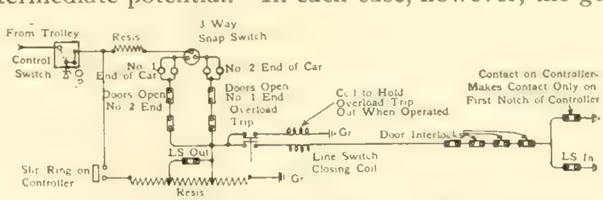


FIG. 6—DOOR INTERLOCKS WITH SPECIAL OVER LOAD RELAY

eral principles outlined above are applied. The ultimate aim in any such system should be simplicity and standardization, exercising great care to make sure that unessential features which tend toward complicity are not included.

War-Time Dipping and Baking Outfits

J. S. Dean

THE average railway operating man, although a firm believer in the systematic treatment of railway motor windings as an insurance against grounds and burnouts due to snow and water, may be unable to install the necessary equipment to handle this work properly on account of the present scarcity of available funds, labor and material. One company, facing just such conditions as these, "took the bull by the horns" and within a week's time and at a very little expense built and put in operation a temporary emergency outfit to handle this line of work. This apparatus has been in constant service for several months and has given such gratifying results that it is believed worth while to show its construction and give some general information as to how this work is handled for the benefit of other operators who may have to work out a similar solution for this problem.

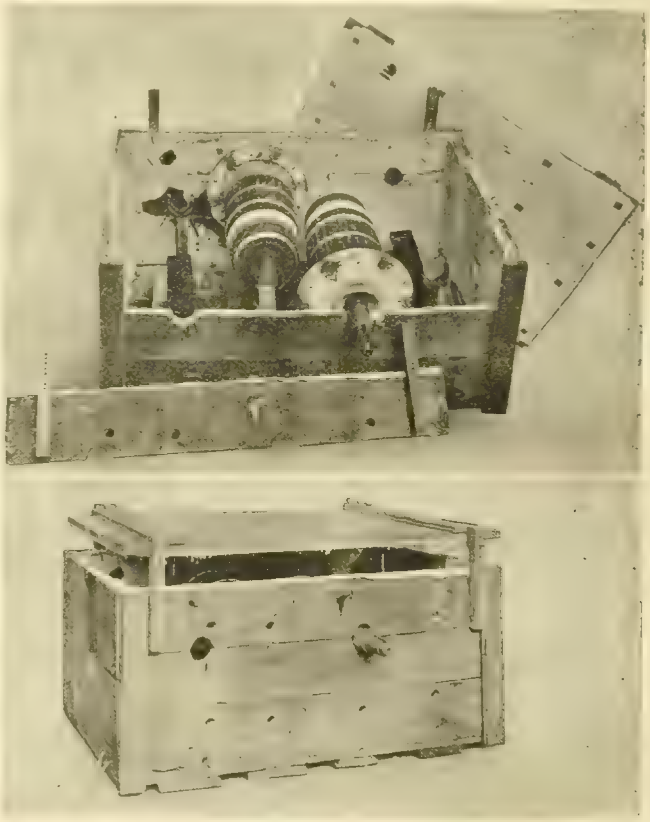
FIGS. 1 AND 2—IMPROVISED DIP TANK

The construction of this outfit can readily be observed from the illustrations without elaborate descriptions. The improvised dip tank is shown in Fig. 1 with an armature ready to be immersed. This tank is an old steel oil drum with the head cut out and with the inside cleaned out and well shellaced. The wooden platform is mounted on heavy castors to make the outfit portable.

In Fig. 2 is shown an armature being drained of excess varnish after dipping. While in this position the armature should be given a quarter turn every ten minutes, to allow the varnish to drain out of all pockets.

The temporary heating and baking oven is shown in Fig. 3 with two armatures in place and having the lid and a section of one side off, preparatory to replacing the armatures. This box is designed to hold four armatures, with the pinion end of each shaft extending outside of the box to allow the armatures to be turned every 15 to 20 minutes while baking, by means of a special wrench hooking into the key way. Electric heaters connected to the 500 volt trolley line are located at the bottom of the oven. Narrow drip pans are placed under each armature to catch the excess varnish. The box shown in Fig. 3 is made of wood, lined with asbestos board to make it as fireproof as possible. The same principle could, of course, be employed with a sheet steel box, lined with asbestos to reduce the heat radiation, thus eliminating the fire hazard.

In Fig. 4 is shown the heating and baking oven with two armatures inside and with the lid in place. The lid is slightly raised to provide ventilation, the height being adjustable to control the temperature inside the oven, which is measured by two thermometers placed in openings in the lid. Holes are bored through all four sides at the bottom of the box to provide circulation of air inside the oven.



FIGS. 3 AND 4—IMPROVISED BAKING OVEN

Much of the material used in the construction of this outfit was available in the form of scrap. Assigning values to this material, however, it is estimated that the entire cost of the materials used was $63.50 itemized as follows:—

Box made out of old shipping box.	
Estimate for material	$12.00
52 sq. ft. asbestos ¼ in. thick	13.50
3 Heating Elements	18.00
Oil drum used for dipping tank	12.00

Rollers for platform	2.00
Pipe for tee device for lifting armature	0.50
Metal for trays	0.50
Wire, sockets and plugs	3.00
Pipe and standards for supporting brackets	2.00

The labor required in assembling the entire outfit, including cutting the head off the tank, building the box and platform and making several special small tools, such as a pipe tee for lifting the armature, trays for catching the drip, a wrench for turning the armatures etc. was 34 man-hours.

While not quite as satisfactory from the standpoint of economical operation as the more elaborate outfits which are designed especially for this work*, the results that can be obtained with this home-made outfit will give entire satisfaction and the outfit will, within a comparatively short time, more than pay for itself in the form of reduced maintenance charges, fewer pull-ins and better service to the traveling public.

*For descriptions of dipping and baking outfits see "Railway Operating Data" in the JOURNAL for June 1918, p. 240; also articles on this subject by Mr. J. V. Dobson in the *Electric Railway Journal* for June 15, 1918; and in the *Street Railway Bulletin* for August 1918. For descriptions of the process of dipping and baking see "Railway Operating Data" in the JOURNAL for April 1918, p. 137.

Acceleration of Cars

LYNN G. RILEY

ONE of the features in the operation of a car most readily noticed and appreciated by the general public is the manner of starting, whether smooth or jerky. A high rate of acceleration can be maintained without discomfort to the passengers, provided the maximum rate of acceleration is built up gradually and then maintained. Recent tendencies toward light weight cars, and power saving by high acceleration rates, have attached increased importance to the feature of smooth starting which requires:—

1—Small increments of tractive effort.
2—Constant or uniform rate of acceleration.

The first depends on the number of control notches, the internal resistance, the inductive and speed characteristics of the motors, and the proper proportions of gear ratio and motive power to the weight and type of car. Most standard equipments possess the proper balance of these characteristics, with a tractive effort increment of about 25 percent on each notch.

The second item, that of constant or uniform acceleration is entirely a function of the manipulation of the control.

HAND CONTROL

Hand control is the accepted standard method of starting power-operated vehicles such as trolley cars, autotrucks and even heavy electric locomotives. There is usually an infinite variety of starting conditions to be met, which require flexibility in operation and a quick response to the will of the operator, with no restrictions other than circuit breaker protection and slipping of the wheels. Most operators soon acquire a sense of speed and relative acceleration which enables them to handle vehicles with a high degree of safety and efficiency.

Hand control was the original method used for operating motor cars, and for a long time was the only method employed. As the electric railway industry grew to include subway and elevated electrifications, it became possible, through the use of remote control apparatus, to place in the hands of one operator the application of a large amount of energy, distributed throughout a train; and it was advisable to place some restrictions on the rate at which power could be applied. This led to various forms of automatic acceleration depending, for the most part, on the constant-current principle, thus providing the fullest protection to the equipment and ideal starting qualities.

At various times, some form of automatic control has been adapted to classes of city and interurban service having more variable characteristics than the usual subway and elevated propositions. Whenever the system is extended beyond those properties where operating conditions are practically constant, with several power units in each train, and having practically no grades above two or three percent, it becomes necessary to study the conditions carefully, and in most cases to provide means to enable the operator to eliminate the automatic features temporarily in order to negotiate some steep grade, or to help a disabled car from the line. As soon as means are provided for cutting out the automatic features, there is a tendency for the operator to use this feature frequently in order to make up time, or for other less important reasons. The real advantages of the automatic features may therefore be lost at a time when they are most needed. Furthermore, any system requiring an unaccustomed manipulation in an emergency is subject to man failure and may be a cause of delays, even though all parts are in good working condition.

AUTOMATIC SYSTEMS

In order to give a clear understanding of the advantages and limitations of the various automatic and semi-automatic control methods which are being used to meet certain specific operating conditions, these systems are listed below, together with a description of the special features used, and the results obtained:—

1—Restrictions by some form of automotoneer handle, which is a mechanical device, imposing certain delay in movement from notch to notch.
2—Constant motor current, or constant trolley current obtained by a current relay.
3—Fixed time acceleration, wherein a certain predetermined time interval is consumed on each notch.
4—Various combinations of the above.

Automotoneer—From time to time various mechanical devices have been attached to controller handles for fixing the maximum rate at which the handle can be advanced. Such devices accomplish the desired results when carefully maintained, but have not

proven universally satisfactory. Most devices can, by skillful manipulation, be put through a complete cycle in about three seconds, which is entirely too fast to meet average conditions and, in addition, permits the operator to accelerate in an erratic manner.

Constant Motor Current or Constant Trolley Current—The current relay came into use primarily in connection with multiple-unit operation involving remote control for the purposes of safety in operation, and equalization of load between all power units in a train. This is the ideal method of acceleration from the point of view of protection to the equipment, power saving and riding comfort. On elevated and subway roads, or on main line electrifications where the grades are slight, the results secured are very desirable. A constant rate of acceleration can be selected which is correct for all parts of the line, and fairly uniform operation is obtained with variable passenger loadings.

There have been interurban applications where it was necessary to limit the peak load, and current relays have been utilized to maintain approximately constant trolley current for each equipment. This, of course, reduces the rate of acceleration in parallel, which is warranted only under extreme conditions.

A refinement of the constant current acceleration method is to adapt the current or tractive effort during acceleration to the loading of the equipment. This involves an automatic means of adjusting the current relay in proportion to the load in the car so that the actual accelerating rate is constant, regardless of the load. This is advantageous where schedules must be maintained through "rush hour" periods and where headway between trains is close.

In extending the current limit system to city and interurban equipments where variable grade conditions are met, it has been found desirable to provide some means for rendering the limit inoperative under abnormal conditions. It often occurs that one or two steep grades on the system require much more than the normal current in starting. Similar conditions obtain when passing around sharp curves or when hauling disabled cars. The automatic equipment may be provided with a spring-return short-circuiting switch, permitting operation at will in excess of the current setting; or it may be so arranged that the operator advances notch by notch from repeated manipulation of a small spring switch. This simulates the action secured from the automotoneer.

A method which has more "fool-proof" characteristics is to provide two current relays, or a compound-wound relay, and temporarily increase the current setting when necessary, but at the same time retain the advantage of final limitation of the amount of current.

The standard arrangement for automatic equipment has been to provide only three master controller positions, switching, series and parallel. However in city service it is desirable to include positions for all of the series notches, in order to meet the variety of slow speeds encountered when operating in dense traffic.

Fixed Time Acceleration—Wherever constant current acceleration is effective with or without the adjustment in proportion to load, the result is practically the same as can be obtained by consuming automatically a fixed amount of time on each notch. The time basis is quite as effective in securing smooth acceleration and ultimate protection to the equipment, but has the disadvantage of not being applicable to roads having variable grade conditions. It is, however, a good compromise between hand acceleration and full automatic acceleration, without some of their disadvantages.

Combined Current and Time Limit Acceleration—The average city and interurban service consists of a large percentage of starting on fairly level track with only an occasional start on a steep grade. Constant current acceleration covers the majority of starts successfully; but on the other hand, any limit cutout device requires rather more frequent manipulation by the operator than is practicable. If, instead, a fairly long time element feature is superimposed on the constant current accelerating system, (the time element being approximately correct for the steepest grades and coming into effect only after the current relay has been delayed in operation), the result is to provide an equipment having all the advantages of constant current acceleration and one which is still capable of negotiating any abnormal grade or increase in load, without reliance on the judgment of the operator. It would also be possible to reverse the arrangement and make the time limit effective for normal operation and the current limit effective only to restrict the maximum current.

CONCLUSION

By far the greater number of equipments now in operation are accelerated on the straight hand operation basis, and it is probable that the proportion will not be altered greatly, for some time to come. In spite of susceptibility to rough starting and abuse, hand control methods hold their own against the automatic systems, mainly on account of their simplicity and flexibility of application. However, on new equipments there is a general tendency toward automatic and fool-proof devices in connection with doors, signals and other features connected with car operation in addition to the control. The difficulty in securing skilled operators makes this development rather imperative. It is recognized that any automatic control features tend to complicate the apparatus, and that the system must be nearly universal in operation before being desirable for application to any great percentage of installations. There is a certain dividing line where the added complications for the special features offset, in their cost and maintenance, the benefits to be derived from the improved operation. This dividing line depends on the size, inspection facilities and other characteristics of the property being considered, and the local conditions require careful study, if the greatest benefits are to be derived from such automatic features as have been described. When in doubt the rule should be "use hand control."

Impact Testing

E. P. Gooch

THE development of a satisfactory impact test is desirable as a means of discovering certain flaws in steel which can not be found by physical or chemical tests, or which may be overlooked in some cases where only the usual methods of inspection are used.

The specifications upon which steel for car axles and armature shafts is purchased usually require that samples from each heat be tested for certain chemical and physical properties, to insure a steel in which a proper heat cycle has been followed during manufacture and subsequent heat treatments. Such tests will not, however, indicate seams, pipes and general internal mechanical defects which may make the finished shaft dangerously weak, though the physical tests on the sample indicate ample strength. An experienced inspector will generally detect and throw out such shafts, as there are usually "ghost lines" on the surface which indicate unwelded metal or "seams" beneath. Doubtlessly a great many shafts having seams go into service and are never heard from, either because the seam is not at a heavily worked section or because its weakening effect on the shaft is cared for by the large "factor of safety" used in the design. In this case "factor of ignorance" would be a truer term as a smaller factor could be used with equal safety, if the designer could be sure of getting seamless material.

In order to avoid material with seams, the specifications usually include some such provision as:—"A sufficient amount of discard shall be made from each ingot to insure freedom from piping and undue segregation." This is rather indefinite as the proper amount of discard varies with different ingots.

When a shaft with an internal defect is machined, fine lines known as "ghost lines" may appear on the surface and these indicate the defect below. These defects often follow very erratic paths, however, and sometimes will not come to the surface at any point though there may be a pocket which will greatly decrease the strength of the shaft. This is the most dangerous condition, as all of the methods which have been mentioned would indicate good material and the shaft would probably be passed without question. When the pocket is large, it can be detected by mounting the shaft in a sling and "ringing out" with a hammer. That is, the shaft is struck a sharp blow with a light hammer, which will cause a good shaft to give out the clear tone of a bell, while a shaft with a large internal pocket, materially affecting the cross-section, will give a dead sound, which is readily recognized.

The impact test has been used to find seams in steel rails by making use of the decreased resilience of the material due to the hidden flaw. The test is made on a sample which is left over after the standard lengths have been cut from the rolled stock. The sample is always taken from the end which is most apt to have seams; that is, the end which was originally the top of the ingot. This piece is mounted on a very heavy, spring supported anvil with a certain distance between supports. A heavy weight, or "tup", is dropped from a definite height on the point midway between supports. The permanent deflection of the sample will be within certain limits for good material. The test as made by one manufacturer requires a 20 000 pound anvil with a 2000 pound tup and seven feet between supports. The drop is varied to suit the different sizes to be tested.

Such a test for shafts and axles is desirable but it should be so modified that the test could be made on the piece to be used instead of a sample. This is especially important where shafts have been heat treated, as the special treatment will either increase the size of the cracks and seams or will magnify the effect of the flaws, since the heat treated material, though showing physical tests indicating greatly increased strength, possesses such characteristics that failure may result from more or less rapid growth of the initial defect.

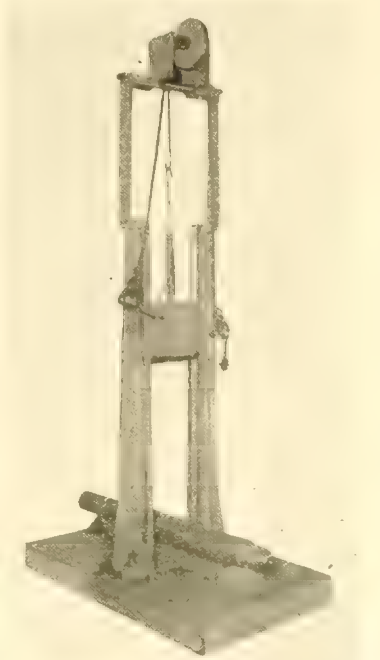


FIG. 1—IMPACT TESTING MACHINE

In order to make the test on the piece which is to be used, it is necessary to keep the acting forces within the elastic limit of the steel so that the shaft will not be given a permanent deflection. It is also desirable to have the test so simple that it is feasible to apply it to all shafts of an order and not to just a few. If such a test could be made reliable, the designer could logically use a smaller "factor of safety" than is permissible at present.

An attempt was made to develop such a test for use on railway motor shafts of diameters from two to six inches which would give the desired result with as simple apparatus as possible. The impact testing machine illustrated was assembled from parts found in the factory and no special castings were made.

The base is a 2000 pound block of cast iron smoothed on the top surface and resting on a thin layer of sand over a brick floor. The guides for the falling weight were taken from a small drop hammer and were bolted to the iron base. On top of these guides are straps supporting the pulley at sufficient height to al-

low use of the full length of the guides. The hammer is a steel block weighing 100 pounds and is guided so loosely as to allow practically a free fall. In the top is an eye bolt which engages a trigger device that can be adjusted to various heights. The hammer is drawn up to the trigger by a rope which is disconnected before allowing the weight to fall on the shaft. The striking face of the hammer is rounded and hardened to concentrate the blow. The supports are halves of a short length of seven inch axle steel bolted to the bed plate. Each one is 18 inches from the point directly under the hammer giving exactly three feet between supports. The shaft shown in position is for a 200 hp railway motor and is 4.5 in. in diameter. The small block shown in the foreground on the bed plate was used in measuring the maximum deflection of the shaft under impact.

The first work done with this machine was of an empirical nature based on a similar test made elsewhere. The results were negative, so further work was done to see if positive benefits could be obtained. The chief point in question is the stresses induced in the shaft by the impact. It is probable that the maximum deflection of the shaft is a direct measure of the maximum stress, so arrangements were made to measure the deflection of the center of the shaft; that is, the maximum deflection directly below the point of impact.

This was accomplished by using compression cones made of a soft lead babbitt. They were placed directly under the point of impact on the head of a tap bolt which was screwed into a small iron block. The height of the cone was measured with a micrometer caliper before putting in place, the tap bolt was backed out until the cone was in firm contact with the under side of the shaft and the hammer was then dropped. The babbit used has practically no resilience so the final length could be measured and the difference between initial and final height taken as a measure of the maximum deflection. Calculations indicated that the energy absorbed by the cone would be such a small fraction of the total energy of impact that it was neglected in most of the work. However, a check was made by using a piece of paraffin which had been heated until fairly soft though stiff enough to be measured. It was used as a roughly formed cone to measure the deflection in the same manner and indicated that the error due to the babbitt cone was within the limits of error due to other crude features of the test.

Calculations were made on the assumption that a part of the kinetic energy of impact is used in overcoming the inertia of the shaft and that the balance is effective in deflecting the shaft, that is, in producing stress. This assumption made the calculations of deflections and stresses quite simple and it was found that the measured deflections were very close to the calculated values for as large a range of shaft diameters and hammer weights as could be handled with this apparatus.

The check between calculated and measured deflections is close enough to indicate that the maximum stress in the shaft is probably fairly close to the calculated value. But this stress exists only at the section of the shaft directly under the hammer and it decreases toward the supports. If this is the true condition, the test can be of no real value as the most dangerous place for a seam is toward the pinion fit which, being near the end of the shaft, must necessarily be near a support.

Several shafts that were known to be defective near the end were subjected to impact and gave no indication of defective material, though the energy of impact was greater than would have been permissible in a commercial test. As far as was known, none of the shafts tested were defective near the mid-section.

From this it appears that the test should be changed so that the stress in the shaft will be as uniform as possible and will remain high very nearly to the end of the shaft. If this is true, the test should be made with both ends of the shaft firmly held and the blow delivered by a hammer with its striking face so shaped that it will distribute the force over a fairly large area.

A stress diagram for the test as made is shown in Fig. 2. The dotted curve represents the stress diagram for the equivalent static load and the solid line shows the probable shape with the inertia taken into account.

No tests have been tried with the last mentioned conditions, but it is obvious that, if there is anything in this theory, the weight of the drop hammer should be large in comparison with the weight of the shaft under test in order to decrease the effect of the shaft inertia.

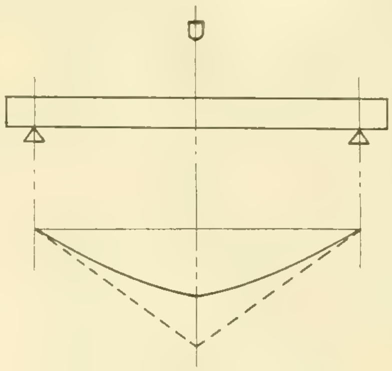


FIG. 2—STRESS DIAGRAM

Also, the length of the hammer face in contact with the shaft during impact should be adjusted so as to make the slope of the stress curve as steep as possible where it crosses the axis of zero stress. This will tend to flatten the other parts of the curve and approach the condition of uniform stress which is desired.

Even if this test can be modified to give nearly uniform stress over the entire length of the shaft, there is still doubt as to whether or not it will show up defects. In a given lot of shafts, made up at the same time and under the same specifications, there will often be considerable variation in physical properties such as yield point and tensile strength. For the test to accomplish its purpose, it is necesary that the stresses set up should not be sufficient to spoil a good shaft for further use but that at the same time, they should be sufficient to cause perceptible overstressing of sections whose effective areas are reduced by defective material.

Such a test is not yet available but would be of great value in testing heat-treated shafts, as well as in many other places, if it could be developed into an easily made test of reliability comparable with that of the various other design factors.

Single vs. Twin Armature Motors

J. M. Labberton

IN THE design of railway motors, the most important objective is maximum power with minimum weight consistent with reliable operation. Next comes space reduction and this generally accompanies weight reduction. Low cost is desirable and essential. Low weight, of course, tends toward low cost until intricacies and complications of design along with the use of expensive materials cause costs to rise.

A problem which frequently must be solved in locomotive design is the determination of the proper type of motor for a given type of drive. The first single-phase motor used in connection with the quill type of drive* was gearless. That is, the quill was pressed directly into the armature spider. This motor is highly successful in the high speed passenger service to which it was applied but it is evident that this type of motor does not lend itself readily to slow-speed freight service, where relatively high tractive efforts are required, for the following reasons:—

The armature revolves at the speed of the driving wheels. The high torque required would necessitate large armature diameters which in turn call for large diameter drivers. These large drivers would immediately lower the tractive effort and render available a high maximum speed. But the speed limit of the locomotive on ordinary track would be reached before the peripheral speed limit of the armature is reached. And since the desired object is high tractive effort with relatively low maximum speed, this type of motor leads to uneconomical design—it requires too much weight for the power produced.

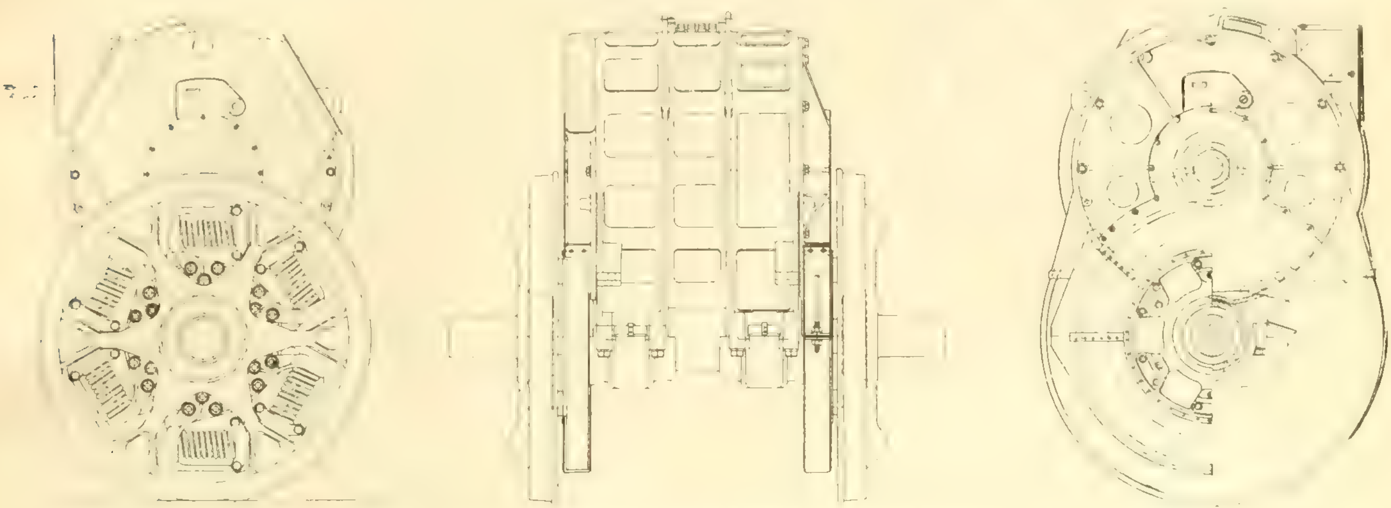


FIG. 1—OUTLINE OF SINGLE-PHASE SINGLE ARMATURE MOTORS
Used on the New York, New Haven & Hartford Railroad.

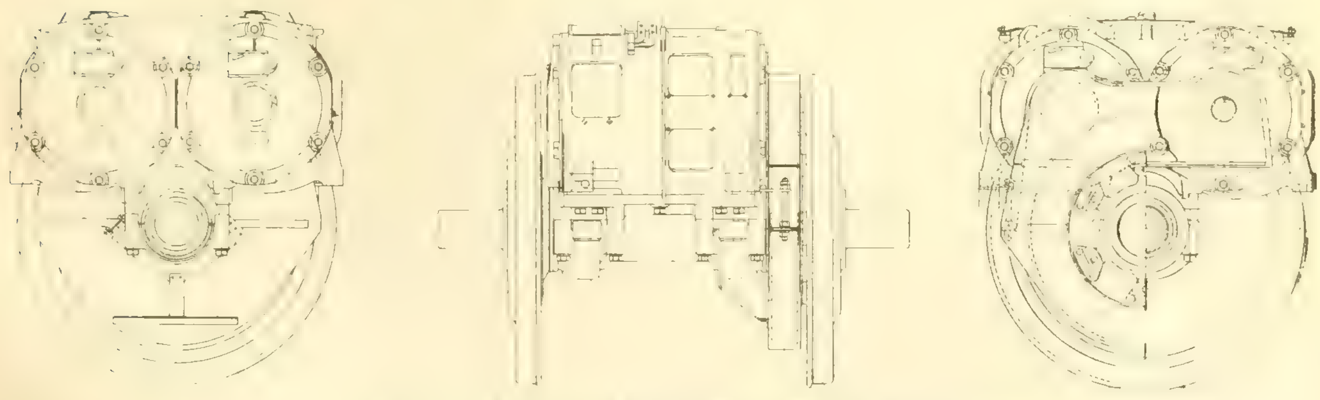


FIG. 2—OUTLINE OF SINGLE-PHASE TWIN ARMATURE MOTORS
Used on the New York, New Haven & Hartford Railroad.

Thus it follows that to produce a motor suitable for either freight or passenger service, some other design than the gearless quill-mounted motor is necessary —so the next type of motor applied to the quill drive was one geared to the quill instead of direct connected as was the gearless type. This geared motor had a wider scope because, by the aid of different gear ratios, it was possible to vary the tractive effort and speed, the horse-power remaining constant.

*See article by Mr. Hardcastle in the JOURNAL for Oct., 1917, p. 414, for a description of this quill drive.

This first geared-to-quill motor was a single-phase, 25 cycle motor. On account of the high torque to be transmitted, an extra long pinion face was necessary, also if one pinion had been used, the shaft at this point would have had to be extra large to care for the excessive bending and torsional stresses. Therefore, a pinion was used at each end, keeping the total face length to the amount necessary and dividing the bending and torsional stresses. This made two gears necessary.

The maximum speed of most railway motors is limited by the strength of the band wires around the armature. For a given peripheral speed of the armature, the tractive effort produced at the wheels varies almost directly as the armature diameter. In other words, torque varies approximately as the square of the diameter (with constant ampere conductors per inch) while for a constant speed in revolutions the peripheral speed varies directly as the diameter. Take for example a locomotive with a gear ratio R such that the motor revolutions per minute are equal to the locomotive

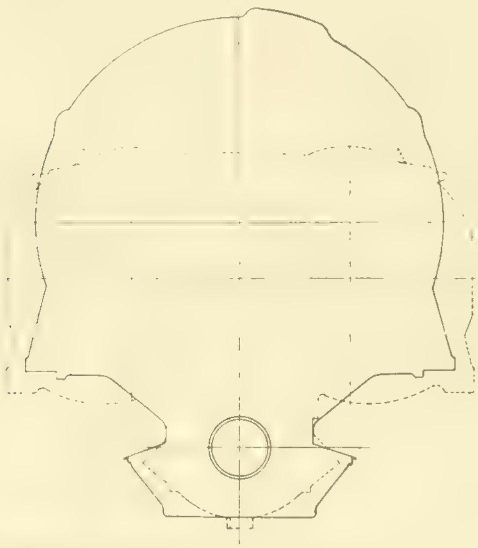


FIG. 3—OUTLINES OF SINGLE AND TWIN ARMATURE MOTORS SUPERIMPOSED

miles per hour when multiplied by R. Let the rated tractive effort be TE and the motor torque T. Suppose the diameter of the motor be increased to twice its original size. In order to keep the peripheral speed the same, R must be changed to $2R$ and the torque is now 2^2T or $4T$. But on account of the changed gear reduction, the tractive effort is now twice what it was originally.

The motor weight varies approximately as the square of the diameter, the length remaining constant. Where motors are not limited in dimensions, the weight per unit output decreases as the output increases. But the length of railway motors mounted on axles is limited. Hence as the tractive effort increases in this type of motor the weight of the motor per pound of tractive effort increases approximately as the square of the tractive effort. This is a very undesirable feature because the tendency of the railroads is toward higher powered locomotives.

The idea immediately presents itself that the locomotive be built with a large number of wheels and quills with small motors. This idea is immediately dispelled on realizing that it is futile to save motor weight if weight is immediately added by using a large number of heavy driving wheels. Anyway, if the motor is not

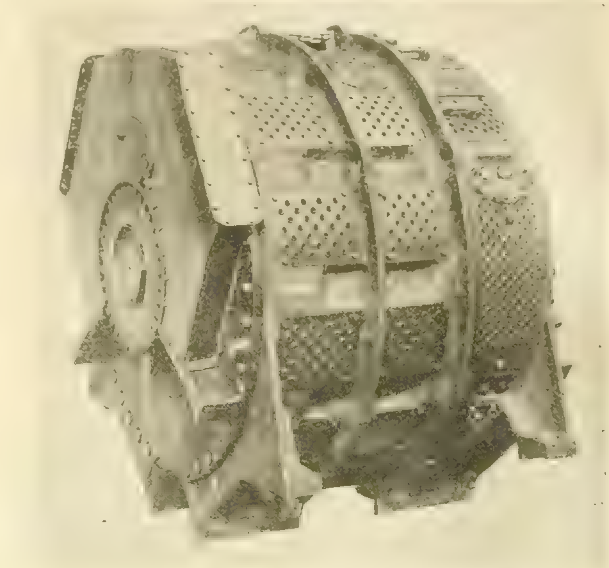


FIG. 4—THE SINGLE ARMATURE MOTOR

large enough to give the full power the pair of driving wheels can use, the design is uneconomical. Therefore, the next logical thing that can be done is to mount a number of smaller motors on one quill and pair of drivers. Unfortunately this number is limited to two if accessibility of brushholders is retained. In time this difficulty may be overcome.

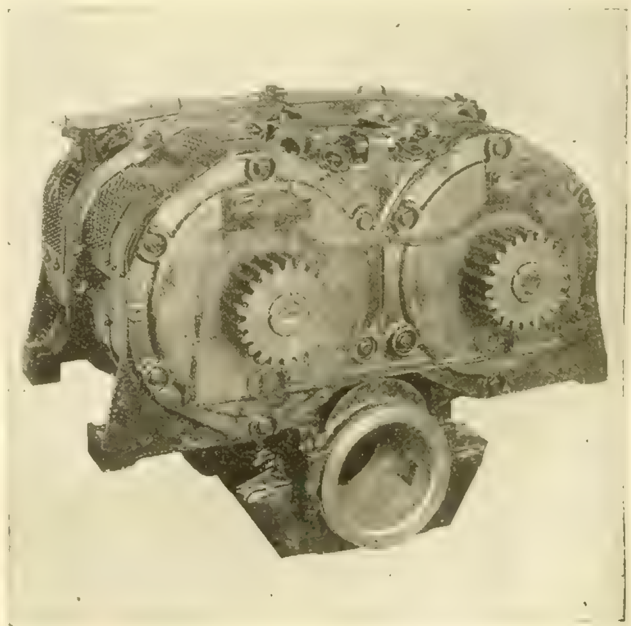


FIG. 5—THE TWIN ARMATURE MOTOR

On closer study of this scheme it will be seen that there are still further advantages. The two pinions, one on each shaft being sufficient, can now mesh with a single gear. The elimination of the other gear not only saves weight but renders space available for lengthen-

ing the motor. A small railway motor is also easier to manufacture than a larger railway motor. The commutator construction and the setting of the brush neutral is far easier on a small motor. Repair parts are cheaper for the smaller motor and less apparatus is kept out of service in case of failure.

The moment of inertia of two small armatures is less than that of one large armature, therefore the springs of the quill drive system receive less punishment under conditions of chattering wheel slip. The mechanical dimensions of the twin armature outfit are better suited to locomotive application than are those of the single armature motor. This is true because the equipment deck in the locomotive can be placed lower in the cab. The equipment deck must be placed just over the tops of the motors. The lateral dimension of the twin being longer, the twin motors occupy space under the equipment deck that with the single motor would be wasted.

The control can be cheapened slightly in some cases by connecting the two armatures permanently in series, because the voltage would thereby be doubled and yet, in case of trouble, no more power need be cut out of circuit than if one large low voltage armature is used.

In view of all the foregoing, twin motors were designed and built to supersede the single armature motor mentioned above. The two motors are compared in Table I. It can be seen from Table I that the twin motor brush length was increased over that of the single at the expense of fan length. It was impossible to save all the space occupied by the extra gear of the single motor on account of the housings, which were designed to occupy mostly the space under the end bell. This could not be done on the twin armature design because of the small diameter, consequently the housing had to occupy space that was previously occupied by the gear. Therefore, from the above, it is seen that the twin motor is virtually the same as the single inasmuch as the pole flux and conductors per pole are approximately the same. The torque has increased in proportion to the conductors and poles.

TABLE I—COMPARISON OF TWIN AND SINGLE ARMATURE RAILWAY MOTORS

	Twin	Single
Core length, in.	13	13
Armature diameter, in.	22	39.5
Number of slots	42	84
Continuous pole flux, kilolines	3600	3300
Brush width, in.	⅜	⅜
Brush length, in.	9	8
Radial duct or fan length, in.	1⅛	2
Number of poles	6	12
Commutator bars	252	504
Armature conductors	504	1008
Continuous torque, ft. lbs.	1000	3500
Continuous amps.	500	930

FIG 6—THE NEW YORK, NEW HAVEN & HARTFORD LOCOMOTIVE TRUCKS WITH SINGLE ARMATURE MOTORS

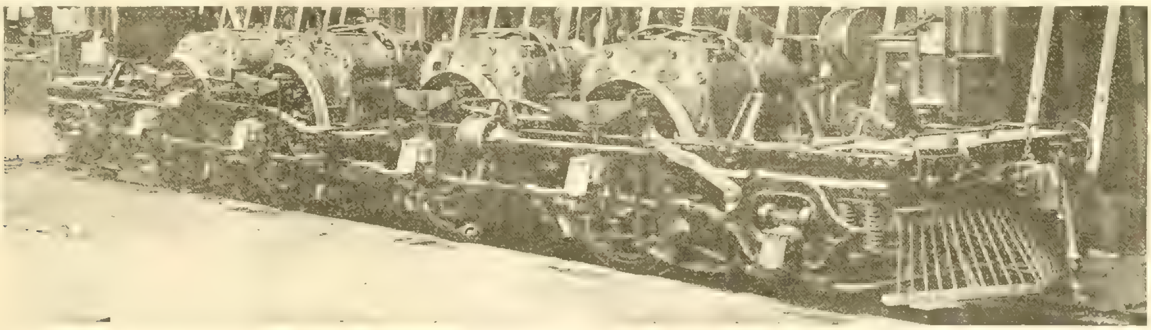


FIG. 7—THE NEW YORK, NEW HAVEN & HARTFORD LOCOMOTIVE TRUCKS WITH TWIN ARMATURE MOTORS

Now consider this twin motor applied to some service where the single motor is operating. Assume the single motor to be mounted on 63 inch drivers with 86 tooth gears and 27 tooth pinions, and since the motor torque is 3500 ft. lbs., the tractive effort (neglecting gear loss) will be 4250 lbs. per pair of drivers. Taking the maximum allowable peripheral speed of the armature as 8000 ft. per min. the maximum speed of the locomotive will be 45.5 miles per hour.

Next consider this same truck and in place of the single motors mount the twin outfit with 17 tooth pinions and a 97 tooth gear. Since the motor torque is

1000 ft. lbs., the tractive effort (neglecting gear loss) will be 2170 lbs. On the same basis as before the maximum allowable speed of the locomotive will be 45.6 miles per hour. But there are two armatures, so the tractive effort per pair of drivers will be 4340 lbs. for the twin set compared with 4250 lbs. for the single with maximum allowable speeds of 45.6 and 45.5 miles per hour respectively. Therefore, the performance of the two motors is practically the same. The starting or maximum tractive efforts of the two motors would be practically the same also.

But what is gained by going to the new design? The weight of the single motor with gear case, quill caps and quill bearings is approximately 14 000 lbs. The weight of the quill drive and details exclusive of wheels is approximately 6165 lbs. This makes a total of 20 165 lbs. approximate for the motor complete with drive.

The weight of the twin motor with gear case, quill caps and quill bearings is approximately 12 830 lbs. The weight of the quill drive and details exclusive of wheels is approximately 4105 lbs. This makes a total of 16 935 lbs. approximate for motors complete with drive.

The saving in weight of the new design over the old is therefore approximately 3230 lbs. and this is at once reflected in first cost and maintenance of the locomotive. The advantages of the twin over the single regarding chattering wheel slip were found to be real—the life of quill springs under twin motor application being much longer.

Many locomotives have been built using this type of motor and a large group of both alternating-current and direct-current motors are now in the process of manufacture.

The Engineering Evolution of Electrical Apparatus—XXXIII

The Development of the Street Railway Motor in America

B. G. Lamme

The following article is contributed by one who took an active part in some of the earliest commercially successful electric railway developments and has been closely in touch with all later developments. His direct knowledge regarding the details of developments by organizations other than the one with which he has been identified is necessarily limited. The latter, however, of which he is now chief engineer, happens to be one of the two surviving railway motor builders of the many which started in the traction race. No claim is made that this article covers the history of all railway motors; it is rather the history of the author's own experience in this very interesting field. In the preparation of this article, the old time associates of the author were called upon for data and reminiscences, and he is particularly indebted to Mr. N. W. Storer for certain details with which the latter was personally more familiar. The present article is limited to street railway motors, although at first it was intended to cover all railway motors, including interurban and main line, along with controllers and control systems. However this was found to be too extensive a field for one section, so the remainder of this subject is left for discussion at a later time. (Ed.)

Railway motor development in America began back in the early 80's but much of this was of a purely pioneer nature and, while it left its impress, in most cases it was not a lasting one. On the other hand, certain of this early pioneer work led directly to the commercial railway motor of the later 80's. It is not the intention to go into this very early history, but to take up the development at the period where it had become more or less commercial.

Principal among the pioneers in this work may be mentioned—Van Depoele, Henry, Daft, Bentley-Knight, Sprague and Short. Some of the railway systems brought out by the early inventors simply flashed up for a short time and then disappeared. Others came and, through merit, stayed until forced out of the field by later developments, many of their good points being embodied in the later systems. The Van Depoele system, with its under-running trolley, left its impress on the future systems in the form of the under-running trolley itself, which has been used almost universally since. Professor Short, with his series system attracted some attention for awhile but, being defective in certain fundamental principles, this system disappeared in favor of the parallel system, which Short himself later adopted. The Sprague system, which came a little later than some of the others, was along more nearly correct lines. It contained certain good fundamental principles; it persisted longer than the other early systems. and eventually established electric propulsion as the coming system of traction for street railways, etc. This will be referred to more completely under the description of railway motors.

Railway Motors

Practically all the early railway motors which were commercially successful were of the double-reduction gear type, i. e., there were two sets of gears between the armature shaft and the car axle. There were two reasons for this, namely, the comparatively slow speed of the cars of those days, and the high speed of the motors, necessitating something like a ten-to-one speed reduction. In most of these designs the motors themselves were suspended from the car axle and were connected thereto by means of spur gearing. In a few

special instances attempts were made to drive the axles through bevel gears, one motor being connected to two axles. None of these survived. Also, chain drive was used on the early Van Depoele system.

By 1889 the electric railway had become quite firmly established. Even at this early day the most successful systems had certain points of similarity, which apparently had some bearing on their success. At this time, the Thomson-Houston (a development of the Van Depoele system), the Sprague (Edison Company) and the Short (Brush Company) systems were at the fore and all were apparently quite successful. Early in 1890, the Westinghouse Company entered the field with a street railway system, thus making four principal manufacturers. Thereafter for several years these four systems were the leading ones on the market. Gradually two of these dropped out, or combined with others, leaving the General Electric (Thomson-Houston and Edison) and the Westinghouse as the only large

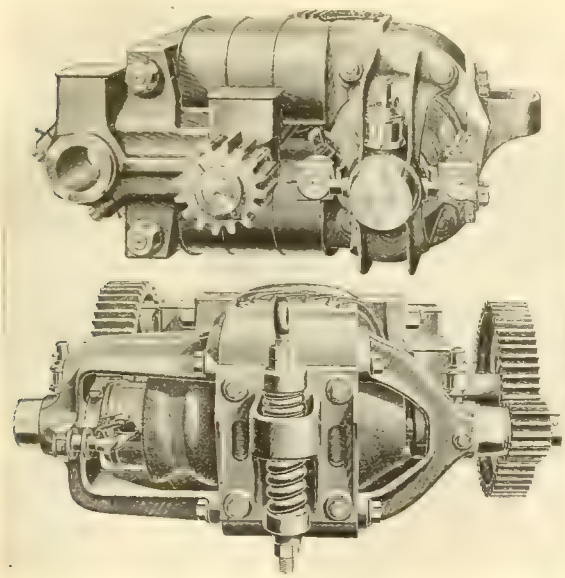


FIG. I—SPRAGUE DOUBLE REDUCTION MOTOR—1889

manufacturers. Therefore, the following description will be confined largely to the motors of the four earlier systems and the two later ones.

SPRAGUE RAILWAY MOTOR

The Sprague electric railway motor system of 1888 to 1890 was unquestionably the most perfect one of that time from the standpoint of control and economy of operation. This was due principally to certain fundamental features of design, which had been carried to the utmost. This motor was of the two-pole type. The armature was of the surface-wound type with several layers of wire. It is obvious that such a motor was inherently poorly protected and, from the present standpoint would be considered an extremely doubtful piece of mechanism to place under a car. However, in those days, all other makes of motors were just as questionable and, therefore, this motor did not suffer by comparison.

The interesting feature about this motor was in the method of starting and speed control. The field structure was made of a good grade of wrought iron of high magnetic permeability. The field coils were wound in three sections of different sizes of wire and different numbers of turns and the field windings were so proportioned that, with all the field coils in series at start, a heavy torque was obtainable with a very small starting current, thus avoiding overheating the fields without the use of a starting rheostat. However, it should be said that, with all the field coils in series, the combined resistance of the armature and field was sufficient to fix the starting current at a relatively small value. Following the series starting position, by series-paralleling of the field coils, various combinations of speed were obtainable up to the maximum desired. Here was a system where all starting and controlling was done without external rheostats, a very economical method of operation and one which has possibly not been exceeded in any of the later commercial direct-current methods of operation. This was due largely to the relatively high speed of the armature of the double reduction type and to the fact that the field magnetic flux could be worked over a very wide range, while the total motor capacity was small compared with modern practice. These favorable conditions disappeared largely in the later, lower speed, single reduction motors.

While this early Sprague motor was a very fine one from the viewpoint of economy of power yet, according to the writer's experience, it did not have the ruggedness for emergencies found in some of its competitors. The very element which made it so economical, namely, the series-parallel field windings and the absence of a rheostat, made it more delicate in emergency conditions which required abnormal currents for prolonged periods; such as pushing snow plows, for instance, during severe storms. In some cases the Sprague motor proved very inferior to some of its competitors, due to overheating when running at low speeds. Nevertheless, with all of its weaknesses, this Sprague double-reduction motor must be considered as the high class one of its day.

THE THOMSON-HOUSTON MOTOR

In general, the Thomson-Houston motor was of the same general type as the Sprague. The magnet core was of wrought iron, or equivalent material. The armature was of the usual surface-wound type. Unlike the Sprague motor, speed control was only partially obtained by varying the field strength. The field was wound with loops or taps brought out near the middle of its length. For starting and acceleration, the full field winding was used with a rheostat in series. To accelerate, the rheostat was cut out gradually and, for still higher speed, only part of the field winding was used, the other part remaining idle. Thus there was no true series-paralleling of the field windings. This method of operation, therefore, was less economical than the Sprague arrangement but, on the other hand, the proportions of the field winding and the rheostat

were such that the motor could stand more severe conditions during starting and acceleration. The field magnetic circuit was apparently much more highly saturated than that of the Sprague motor, resulting in a flatter speed curve. In consequence this motor would run somewhat faster than the Sprague on heavy load, and was considered by many operators as a better hill climber, simply because it ran faster up hill. Due to its lower saturation, the Sprague motor tended to drop off very considerably in speed on heavy grades and this was considered an evidence of weakness, that is, of lack of power; whereas, in fact, it was a real merit in those days of limited power supply. The range of current taken by this Thomson-Houston motor, due to its flatter speed characteristics, was apparently considerably greater than that of other types of railway motors. The commutation on this motor was apparently very good compared with the Sprague motor. In fact, the latter, according to the writer's experience, appeared to be one of the poorest commutating motors on the market. Nevertheless, due to its special method of control and the consequent smaller currents required, this poorer commutation did not seem to have as harmful effects as one would infer from looking at it. In other words, the commutator of the Sprague motor had about as good life as any of the others.

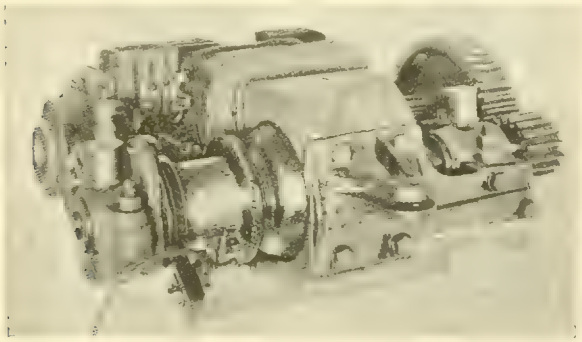


FIG. 2—THOMSON-HOUSTON DOUBLE REDUCTION MOTOR—F-30

One thing that counted against good commutation on these early motors was the extremely heavy mica between commutator bars. One-sixteenth inch mica was not at all uncommon on such motors and when trouble developed at the commutator, there was frequently a cry for thicker mica and, as a consequence, the thicker the mica the greater the trouble. This persisted up into the later motor practice and was a source of much trouble for several years.

THE SHORT MOTOR

In construction, the Short railway motor was a close relative of the Brush arc machine, that is, its magnetic circuit and other parts were arranged very similarly to that of the arc machine. A disc armature was used with pole faces presented at the sides of the armature. The early machines were of a two-pole type and later this general construction was developed in four poles in connection with later Short systems. The armature of this Short motor was of a toothed type, this also being apparently a development from the Brush arc machine. It is questionable whether the teeth on this armature were proportioned for magnetic purposes or for mechanical. The teeth were few in number and the slots between were quite wide. Magnetically the arrangement might be considered as some improvement over the surface-wound type, but the proportions were not such as would be considered effective, even in the true slotted types of armatures which followed two or three years later.

This Short type railway motor contained a number of more or less fundamental defects, which in the end were sufficient to rule out the type. In the first place, due to the disc type of construction and side poles, there was a tendency for strong unbalanced side pull between the armature and the pole pieces, and strong thrust collars were necessary to overcome this. On account of this arrangement no end play was permissible, as in ordinary railway motors. In the second place, the method of connection between the commutator and armature winding was a very awkward one, since the armature leads had to be carried radially to the shaft and then along the shaft to the commutator. In the third place, with this general construction, a non-magnetic spider had to be used as a rule. This meant a construction which was not as solid or as durable as was obtainable with the cylindrical drum type of armature with the laminations pressed directly on the shaft or upon a cylindrical supporting spider.

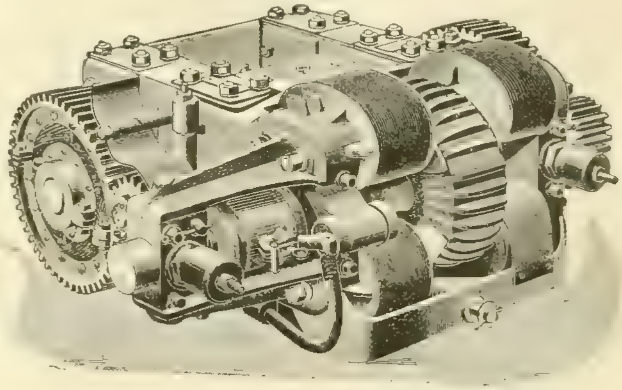


FIG. 3 SHORT DOUBLE REDUCTION MOTOR—1890

Even with all these defects this type of machine was continued for several years and was carried into the single reduction type and into the gearless, when the construction was somewhat simplified by the use of four and six poles respectively. However, the type was destined to disappear due to fundamental defects, and apparently only the persistency of Professor Short, who originated it, kept it going as long as it did. Eventually Professor Short himself abandoned the type, when he put out the Walker motor, which will be mentioned later.

WESTINGHOUSE MOTOR

The remaining double-reduction motor, which made any considerable impression on the railway field, was the Westinghouse. This was brought out in the Spring of 1890, somewhat later than the other sys-

tems mentioned. In general type, this motor was quite similar to the Sprague and the Thomson-Houston. However, the field core was of cast iron and the motor was, therefore, somewhat heavier than its competitors. The armature was surface-wound and similar to almost all railway motors of that time. The field winding was arranged in two coils without metal "bobbins", with different sizes of wire and different numbers of turns. For starting, all field windings were in series and the rheostat was connected in series. For higher speed the smaller winding was cut out. Obviously, this arrangement was electrically very similar to the Thomson-Houston.

The principal differences were in details of the mechanical construction. The fields were hinged to the supporting yoke in such a way that they could swing back to give more easy access to the armature. Also the gears were enclosed in gear cases which were filled with lubricating grease. The purpose was to overcome

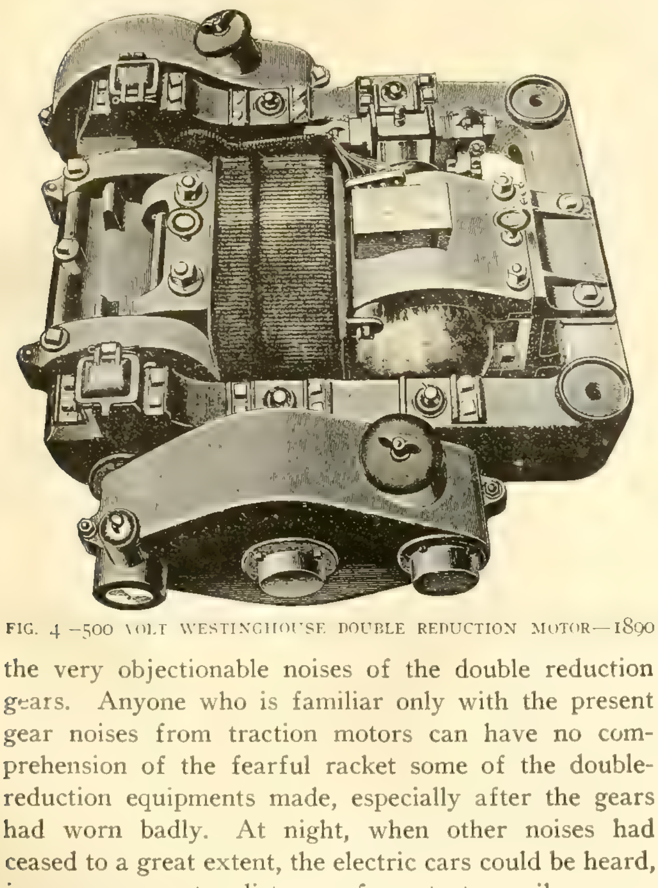


FIG. 4—500 VOLT WESTINGHOUSE DOUBLE REDUCTION MOTOR—1890

the very objectionable noises of the double reduction gears. Anyone who is familiar only with the present gear noises from traction motors can have no comprehension of the fearful racket some of the double-reduction equipments made, especially after the gears had worn badly. At night, when other noises had ceased to a great extent, the electric cars could be heard, in some cases, at a distance of one to two miles.

On many of the early double-reduction equipments cast iron gears were used and, as a consequence, stripped gears were not uncommon. In those days cars were operated under conditions which no one would dream of attempting in these times. In one case, in the writer's experience, a track was being repaired in a certain part of Allegheny City and the only way to get around it was to run up a parallel street and part way over a cross street to the end of the track, which was about thirty feet from the original track. This intervening section, paved with rough cobble stones, was overcome by getting the car up to considerable speed and running across the space by means of inertia. If the car did not get across, then a long wire was carried from the controller on the car back to the end of the track and thus a "ground" was obtained for covering the rest of the way. In one instance, a car was stalled in this section and the motorman left his controller on "full" position while he carried his conducting wire back to the end of the track. Upon touching the rail, the car did not move out of its steps, so to speak, but simply gave a jerk and the gears were stripped.

The Westinghouse double-reduction motor was made of cast iron, but its operating characteristics were quite comparable with the other systems, except the Sprague. However, although a considerable number of these motors were put out in 1890, the writer, along with certain other engineers of that time, did not believe that any one of the then existing railway systems was final, due primarily to the fact that the motors were too susceptible to injury, not being sufficiently protected in view of their location under the car. It was believed that it was merely a question of time when all such motors would have to be rebuilt. The first Westinghouse motor was put in service in Allegheny, Pa., on July 3, 1890. This date is given to indicate the short time which elapsed before the writer, who had been instrumental in getting out this Westinghouse system, undertook to get out a radically different system to supersede it.

GENERAL TREND OF DEVELOPMENT

The above brings us up to the period when the single reduction motor was developed. The double reduction motor very quickly disappeared from the market after the single-reduction arrived, but it must be said that the double-reduction motor, and the early system as a whole, left its impress on the future development. There were several features in this early development which survive even to the present time, such as the use of carbon brushes, series wound motors, motors suspended from the axles and geared to them, enclosing gear cases with grease lubrication, mummified field coils, under-running trolley, platform controllers, etc. The fact that a number of these features have survived in very much their original form indicates that they were fundamental in their nature. The early designers of such systems must be given credit for a quite comprehensive knowledge of the real problem of electric traction. Their short-comings were more in their inability to construct, than in their lack of knowledge of the correct principles.

Those early days were times of experimentation by the operators as well as the manufacturers and it was not an unusual thing for a small electric system to have two or three different types of equipment and, in one case in a small system near Pittsburgh having seven cars total, there were five different kinds of equipment at one time. Furthermore, the operator was rather proud of the situation. In this early work there were a number of points which were taken very seriously in those days, but which, from the present viewpoint, are rather amusing.

For example: The earth was considered as being of negative potential and, therefore, many engineers (or so-called engineers) held the opinion that the positive terminal of the motor could not be connected with safety to the ground side as there was danger of a short-circuit. The writer spent many weary hours attempting to show some people the absurdity of this opinion, but, generally, without success.

Also another subject on which there was considerable controversy was that of large-diameter vs. small-diameter armatures. Many people contended that even with the same horse-power and speed a large diameter armature necessarily gave more tractive effort than a smaller diameter.

There was also much discussion concerning the speed and power characteristics of the various motors. Certain makes of motors ran faster up hill than others. The Sprague motor, for instance, was a slow hill climber; on the other hand, the Thomson-Houston double-reduction motor was a fast hill climber and the Westinghouse was in between. As a rule, most people believed that the Thomson-Houston motor was, therefore, a more powerful one than either of its competitors. The writer had quite frequent contentions that the Sprague type of motor, with its drooping speed characteristics was more nearly ideal for railway work than the Thomson-Houston with its flatter speed curve. His claim was that the drooping speed characteristics called for a more uniform and a lower average current from the generating system and, therefore, required less generating plant. He contended that the place to make speed was on the level and not on the hills. Apparently this argument has never been definitely decided in favor of either viewpoint, but today it is generally recognized that the steeper speed characteristic is a more economical one as far as the generating or transmission system is concerned.

In comparing the merits of these early types of motors, a not unusual test was to couple cars with two different makes of equipments, end to end and then determine which could outpull the other, starting from "rest." Of course, a good deal depended upon the skill of the motormen, but in many cases those motors with drooping speed characteristics had the advantage and, therefore, according to this test, were more powerful, although when it came to climbing hills they were supposed to be less powerful. Here was a contradiction which puzzled a great many people.

One interesting feature in connection with the early motors may be dwelt on more extensively, namely, the use of the series motor. Very early in the development, shunt motors were tried but it was soon recognized that they did not meet practical conditions, and the series motor was adopted exclusively. However, in the use of the series motor itself there were certain differences in practice. For instance, most of the railway systems paralleled the field windings and the armatures, independently. For reversing it was necessary to bring out leads between each armature and its field windings and the field windings of the different motors were permanently paralleled with each other. The same was true of the armatures. Then by means of one reversing switch all the armatures, or all the fields, could be reversed. In the Thomson-Houston system, however, the different field coils and armatures were not paralleled with each other, but separate reversing switches were supplied for each motor. Obviously this required more wiring and reversing switches than the other systems and was a subject of much criticism. But, this arrangement was fundamentally correct, and has come down to the present day. The other methods, with paralleled field coils, were subject to the difficulty that there could be greatly unbalanced currents in the armatures, where the magnetic fields were not of equal strength; whereas, with the Thomson-Houston motors there could only be unbalanced currents between the motors as a whole and not between individual armatures, and any unbalance in the current in the field coils tended automatically to correct the difficulty.

In the double-reduction motors, with their excessively large air-gaps compared with later practice, differences in the magnetic properties of the materials did not count for much because such a large percentage of the field magnetizing force was expended in the air-gaps. However, when it came to the later single-reduction motors, with their smaller air-gaps and higher saturation in the cores, the fallacy in the parallel arrangement of the field coils began to show up quite early.

SINGLE REDUCTION MOTORS

In August 1890, the writer began work on a radically new type of railway motor of only about one-third the speed of the ordinary motor, with a view to using only one gear reduction between the armature and axle. In going into this matter from the electrical and magnetic standpoint, it soon developed that the surface-wound type of armature was impracticable. Furthermore, it became evident that a cylindrical type of field construction with inwardly projecting poles, such as was common in alternators in those days, would furnish magnetic conditions much better than any previous type, *provided more than two poles were used.* The writer then laid out a four-pole field construction with radial poles and external cylindrical type yoke, and with a slotted type of armature. It was at once obvious that such type of machine was inherently better protected than the ordinary construction, due to the external yoke. However, in this general construction one serious stumbling block appeared, namely, the fact that for accessibility only two sets of brushes were desirable with a four-pole armature. This appeared to be quite a problem, for apparently the only known solution was in cross-connecting the commutator at every bar, which was at that time a fairly well-known construction. This construction, however, appeared to the writer to be prohibitive and he, therefore, set out to devise some other arrangement, and in doing so developed the now

well known two-circuit or series type of winding for "drum" armatures. A great deal of criticism appeared in connection with this winding, but the writer was nevertheless sure of the principle and felt confident that it was a correct solution of the problem, and his confidence was sufficient to carry it through to a test. Two trial motors were built of this general construction, in the Fall of 1890. In these two early motors the lower half of the field yoke, or frame, was carried out and upward, forming housings which enclosed the lower half of the field winding and shielded the armature from injury from below. The two brush arms were placed on the upper quadrants of the armature, making them more accessible.

The armatures of these two motors were of the slotted type, with ninety-five slots (one less than a multiple of the number of poles, on account of the two-circuit winding). At first, attempts were made to wind these armatures by hand, but it was quickly recognized that this would be a rather doubtful construction and the writer proposed machine wound coils which were

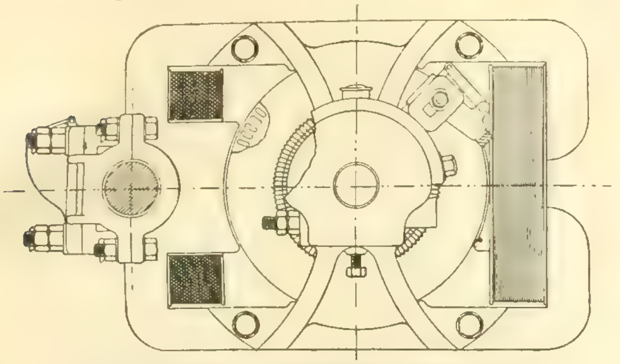


FIG. 5—DIAGRAM OF WENSTROM MOTOR—1890

at once made up and tried on the cores. Various modifications were tried on these first sets of coils and one attempt was made to shape the coils in such a manner that they would all be exact duplicates and could be placed symmetrically on the armature, in two layers in the slots, one-half of each coil being in the lower layer, the other half on top, just as in modern railway armatures. We succeeded in getting about two-thirds of the winding in place in this manner, but then the end parts began to interfere so that we failed in getting the other one-third in place, and this experiment was temporarily given up. It developed later that a little more knowledge of the correct shape of the coil would have allowed a successful construction of this type, and thus one of the big steps in the later development would have been anticipated. However, after several weeks of experimenting, it was decided to put the machine wound coils on in two layers, hammering down the ends of the first layer in order to obtain end space for the second. With this arrangement, machine-wound coils were used successfully and the first two armatures were then wound in this manner, the writer personally winding one of them, although not an experienced winder.

The first completed machine was put on test and at the first trial, for a wonder, it started off and performed admirably over the whole range for which it was designed. The commutation was very good—unexpectedly so—as this was one of the points where trouble was feared. The two-circuit type of winding functioned as expected. By good fortune, one big departure from previous practice proved to be a stepping-stone to later work, namely, in these first machines the mica between commutator bars had been made only 1-32 in. thick; whereas, in double-reduction types of motors 1-16 in. mica was common practice. This "thin" mica, however, was objected to so seriously by almost everybody interested, that on the following motors it was changed to practically double thickness, but with disastrous results, as will be described later. This first Westinghouse single-reduction motor was tested in the Fall of 1890, but was not considered quite ready for the market from the manufacturing standpoint, although in its electrical characteristics it had proven entirely satisfactory. It was decided to improve the motor by hinging the two halves of the cylindrical field to a supporting frame which carried the armature and axle bearings. It was also decided to enclose more completely the lower half of the frame so that the armature and field would be protected from below. The motor was considered to be a very radical step, and it was thought advisable to take ample time in getting it ready for the market.

THE WENSTROM MOTOR

Meanwhile, during this development, a situation arose which materially hurried up the work. The Wenstrom Company came out with a single-reduction motor which was heralded as being revolutionary in character. This motor was of the four-pole type with two salient and two consequent poles. The armature was of a four-pole type. The armature winding was imbedded in holes or tunnels below the surface of the core. This armature was, therefore, one form of the slotted type. This machine created such interest that it was immediately decided to rush the completion of the Westinghouse motor for the next Spring trade, whereas, the former intention had been to continue the double-reduction motor for sometime to come. Moreover, the appearance of this Wenstrom motor immediately hurried all other motor manufacturers in their development of single-reduction motors. Apparently a number of them had already been working on this line, for their new single-reduction motors appeared so quickly on the market, that there was good reason to believe that they had already partly developed the machines before the demand came. Some of these motors were put on the market before they were properly developed and they proved to be merely makeshifts to be superseded soon by radically different types. This Wenstrom motor did not persist as it apparently contained certain defects which put it "out of the running" before it had gotten very far. It, however, hurried the situation very materially.

WESTINGHOUSE NO. 3 MOTOR

The commercial single-reduction motor, which the Westinghouse Company put out in the Spring of 1891

was simply a further development of the experimental Westinghouse four-pole single-reduction motor already described. This motor immediately "took" and a very large number (for those times) was sold the first season. In fact the demand for this motor was so pronounced that the company could not dispose of all of the double-reduction motors on hand partly or wholly completed.

This No. 3 motor might be called the progenitor of the present practically universal type of direct-current railway motor. It contained a fairly large number of the fundamental features found in the present motors. Some of these may be classified as follows:—

1—Four-pole field construction with internal radial poles.
2—Symmetrical flux distribution, thus improving commutation.
3—Four coils all similar in size and shape.
4—Field coils without bobbins or supports, each coil being wound on a form and afterwards insulated.
5—Electrical parts naturally protected from below by the iron-clad construction of the magnetic circuit and frame.
6—Four-pole slotted drum type armature with open slots.
7—Machine wound armature coils, insulated before being placed on core.
8—Two-circuit or series direct-current armature winding, which is in almost universal use at present for railway work.
9—Saturated pole tips.

In addition the first motors built had 1-32 in. mica, which is now a standard for such work. However, on later No. 3 motors, the mica was changed to practically double this thickness, on account of the general insistence that 1-32 in. mica was utterly impracticable from the commercial standpoint. In the early days of the railway motor, thick mica was supposed to be the "cure-all" for all flashing troubles. If the mica did not wear fast enough, and lifted off the brushes, the machine sooner or later would spark and flash badly. The cry would be for more mica and, in some cases, thicknesses of as much as 1-8 in. were used, but without advantage as far as the writer could see, but the claim was made that the trade absolutely required such mica.

The writer and his associates yielded to this demand, with unfortunate results. The motors with thicker mica soon developed blackening and burning at the commutators, and the only direct remedy found for this was undercutting the mica. This was practiced on a number of the first motors put out, but was considered such an impossible practice that it was evident that some other remedy was necessary. Meanwhile the first two experimental motors had been running in regular service on the Second Avenue Line in Pittsburgh, and had developed no trouble whatever from commutator blackening or burning. After an exhaustive investigation of the conditions, the writer recommended going back to the 1-32 in. mica, regardless of any demands to the contrary. A large number of the commutators with thick mica were then replaced with this thinner mica and the results were soon apparent in the fact that undercutting was unnecessary. This was conclusive proof that the thinner mica was a solution of the problem. However, it must be borne in mind that even the 1-32 in. mica of that early date (1891), was inferior to modern mica in wearing characteristics, as it was simply punched out of solid mica, the only sub-division being the splitting up of the mica segments into thin sheets and then assembling again in exactly the same form. "Micanite" or built-up mica did not appear until some time after this.

This No. 3 motor was very heavy for several reasons. It had a cast iron magnetic circuit, it had a relatively low gear ratio compared with later practice, as it used an eighteen tooth pinion and a sixty-four tooth gear. In service, one difficulty soon showed itself, which had not been noticed in the corresponding double-reduction motors, namely, a very decided tendency to unbalance, in the armature currents of the two motors on a car. It was soon found that this was due to unequal counter-e.m.f.'s due to inequalities in field material, slight differences in manufacture, etc. On account of the relatively small air-gap, errors in manufacture produced an exaggerated effect. However, this difficulty was overcome by adjusting the air-gaps of the motors. It happened that this could be easily done by means of the two hinged halves of the fields. This arrangement permitted the motor to be opened slightly

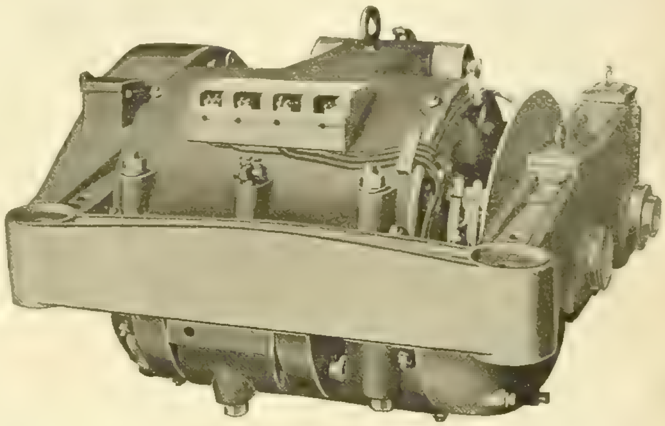


FIG. 6—WESTINGHOUSE NO. 3 MOTOR—1891

at the two opposite joints, so that sheet iron liners of suitable thickness could be inserted in the joints of one motor until a suitable balance in the currents was obtained. It so happened that the Westinghouse Company had on hand a large stock of small compact ammeters built for the Waterhouse arc system, which had practically become obsolete. Little testing sets were made, using two of these ammeters mounted on a supporting base. These were furnished to the customers for use in balancing their car motors. Later the straight series arrangement of armature and fields was adopted and this unbalancing trouble was thereafter negligible.

When the single-reduction motors first came in, one of the subjects for frequent argument was in regard to the torque which such motors could develop. Many people claimed that inherently the single-reduction motor could not pull a car as well as the double-reduction, even at the same horse-power rating, when developing the same car speed. This even went so far as to result in competitive tests. In one case in the writer's experience, a competitive test was run, about 1891, on the Second Avenue Railway under the impression that such a test would prove conclusively that

the single-reduction motors did not have the required torque, and, therefore, would take enormous currents compared with the double-reduction. Local representatives of the Thomson-Houston Company agreed to, and took part in, this test, but apparently without any definite opinions as to which equipment would make the better showing. The test was continued during the greater part of one day, several round trips being taken over the whole length of the system, and current and voltage readings were taken at ten second intervals. An interesting result, noticeable during the progress of the test, was that the Westinghouse equipment seldom took less than 25 to 30 amperes when running light and seldom above 60 to 70 amperes under the heaviest conditions; whereas, the Thomson-Houston equipment at times took as low as 10 amperes and at other times up to 100 amperes. This was just what the writer expected, from his knowledge of the speed characteristics of the two machines, and he did not consider that the tests proved anything more than the general characteristics of the two machines would indicate. However,

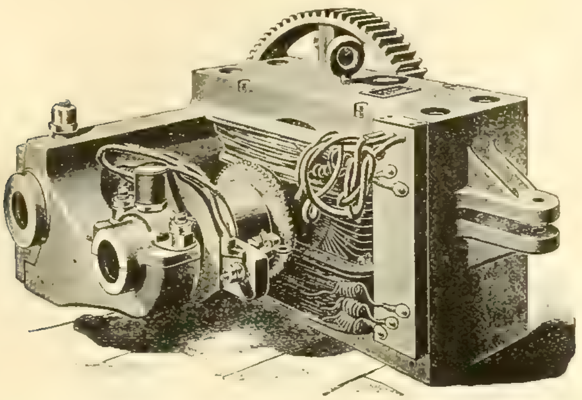


FIG. 7—THOMSON-HOUSTON SINGLE REDUCTION MOTOR—1891

most of those present compared the *maximum* currents taken by the two equipments and drew the conclusion at once that the single-reduction was more economical. The writer, however, did not consider this a just comparison and took the trouble to carefully analyze the whole set of readings and found that the total power consumptions for the two equipments were so nearly equal that differences in the motormen's method of operation could easily account for any discrepancies. As a result of this test many people who heard of it revised their opinions of the pulling characteristics of the single-reduction equipment.

THOMSON-HOUSTON SINGLE-REDUCTION MOTOR (S. R. G.)

This was one of the motors which was rushed on the market shortly after the Wenstrom motor appeared. It was a two-pole machine. The magnetic core was made of wrought iron in order to keep down the weight. The armature of this machine, according to the writer's memory, was of the ring type. From the electrical standpoint this motor was no improvement over the old double-reduction, and the ring armature in reality proved to be much poorer than the drum type used on the Thomson-Houston double-reduction motors. In fact, the only real merit of this machine was in its lower speed, thus allowing single-reduction gears. An attempt was made to protect this machine by an encasing or protecting sheet metal pan underneath. This pan was to a certain extent effective, but unless rigidly supported it made very noticeable noise, due to vibration.

W. P. MOTOR

It was soon recognized that the S. R. G. motor was not a permanent one, so that very soon a new type was gotten out, namely, the "W. P." (weather-proof). This was an enclosed motor and it was, from the electrical and magnetic standpoint, of a very peculiar design. There was but one field coil, placed above the armature. The armature itself was of very large diameter and weight and of the slotted type, with partially closed slots and the winding was of the ring type. The winding consisted of a copper ribbon threaded through the openings at the top of the slots and was wound in place by hand. On account of the magnetic arrangement, a non-magnetic spider was necessary. Also on account of there being only one magnetizing coil there was some stray field out through the shaft and bearings. This, of course, was minimized to a great extent by the non-magnetic spider. Possibly one of the worst features in this W. P. motor was the unsymmetrical commutating zone. Due to the type of the magnetic circuit, the flux distributions were not symmetrical under the two poles. Furthermore, the armature reaction tended to distort the field quite seriously, thus affecting the commutating conditions. Very heavy mica was used in commutator and sparking was so bad that the life of commutator, in many cases, was only a few months. The armature leads had "eye" terminals to permit easy change of commutators.

In order to keep down the weight, this W. P. motor was either made of steel or an iron-aluminum alloy of good magnetic properties. This motor survived for a number of years, but due to inherent defects in its characteristics and construction it was doomed to eventual obsolescence. The ring type of armature and the unsymmetrical flux distributions were two conditions sufficient to condemn this machine, from the present viewpoint. However, it must be borne in mind that in those days certain features were considered very meritorious which now would be looked upon as prohibitive, the ring type of armature being one example. This W. P. motor had its place in the ultimate development of railway apparatus regardless of the fact that it did not survive.

(To be continued)

The Essentials of Transformer Practice-XV

An Approximate Method of Design

E. G. Reed

THE cases of design outlined in section X can be carried out in detail for various types of transformers. The treatment here given is not complete and is intended to be more of a suggestion than of an exhaustive nature. For the sake of simplicity it is limited as follows:—

1. Simple shell and core types with rectangular iron and copper sections.
2. Undivided magnetic circuit.
3. Copper uniformly distributed over the winding space.

The last assumption is approximately true only, as in reality there are fixed insulation clearances, depending on the voltage between the windings and the iron which influence the design to a considerable extent; particularly for the higher voltages.

CAPACITY CONSTANT

The most obvious point from which to start the design of a transformer is to determine the capacity constant N, which is the product of the areas of the iron section A_i and the copper section A_c, from eq. 14, section IV. This equation is,—

$$N = A_i A_c = \frac{7 \times 10^9 \times P}{B\, I_d\, S_i\, S_c\, f} \quad \ldots\ldots (1)$$

Where P is the k.v.a. rating of the transformer, B is the flux density in the magnetic circuit, I_d is the current density in the copper circuit, S_i is the space factor of the iron circuit, S_c is the space factor of the copper circuit, and f is the frenquency of the current.

The values of B and I_d chosen depend upon the iron and copper losses desired and their upper limit is set by saturation of the iron and heating of the copper. Low values for these densities will give low iron and copper losses, and the transformer will have a relatively large amount of material, and therefore be expensive. The value of S_c depends on the capacity rating, voltage and frequency of the transformer.

Example:—What is the capacity constant of a 2300-230 volt transformer which has the following characteristics? $P = 200$; $B = 12{,}000$; $I_d = 1550$; $S_c = 0.4$; $S_i = 1.0$; $f = 60$.

From equation (1),—

$$N = \frac{7 \times 10^9 \times 200}{12{,}000 \times 1550 \times 0.4 \times 60} = 3150$$

DIMENSIONS OF THE TRANSFORMER

Even with a fixed value of N, the transformer is not designed until values are determined for A_i, A_c, b_c, a_c, b_i and a_i, when

$$A_i = b_i a_i \quad \ldots\ldots (2)$$

$$A_c = b_c a_c \quad \ldots\ldots (3)$$

and b_c, a_c, b_i and a_i are the dimensions of the copper and iron circuits, as shown in Figs. 1, 2 and 3. These six variables may be reduced to three as follows*,—

$$\text{Let } X^2 = \frac{A_i}{A_c} \quad \ldots\ldots (4)$$

$$Y^2 = \frac{b_c}{a_c} \quad \ldots\ldots (5)$$

$$Z^2 = \frac{b_i}{a_i} \quad \ldots\ldots (6)$$

X^2, Y^2 *and* Z^2 are used for these ratios instead of X, Y and Z, because of the simplification this makes in the following algebraic work. The sectional areas and dimensions of the transformer may be written as follows, by the help of equations (1), (2), (3), (4), (5) and (6),—

$$A_i = (X^2 N)^{1/2} \quad \ldots\ldots (7)$$

$$A_c = \frac{N}{A_i} \quad \ldots\ldots (8)$$

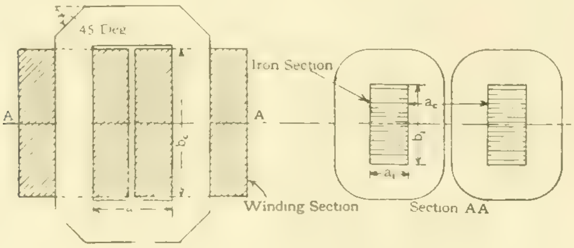


FIG. 1—CORE TYPE TRANSFORMER

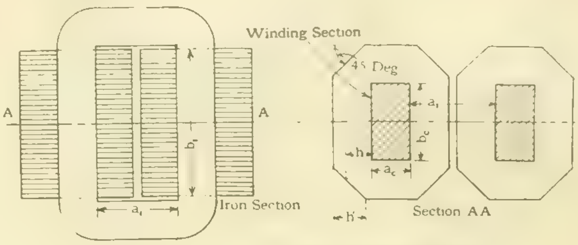


FIG. 2—SHELL TYPE TRANSFORMER

With a section through the winding at right angles to the magnetic circuit.

$$b_c = (Y^2 A_c)^{1/2} \quad \ldots\ldots (9)$$

$$a_c = \frac{b_c}{Y^2} \quad \ldots\ldots (10)$$

$$b_i = (Z^2 A_i)^{1/2} \quad \ldots\ldots (11)$$

$$a_i = \frac{b_i}{Z^2} \quad \ldots\ldots (12)$$

Example:—What are the values of A_i, A_c, b_c, a_c, b_i and a_i, for the transformer covered by the preceding example of the shell type of design, whose value of N is 3150,—when $X^2 = 2.1$; $Y^2 = 2.3$; $Z^2 = 2$?

From equations (7) to (12),—

$A_i = (2.1 \times 3150)^{1/2} = 81.4$ sq. in.

$A_c = \frac{3150}{81.4} = 38.7$ sq. in.

$b_c = (2.3 \times 38.7)^{1/2} = 9.44$ in.

$a_c = \frac{9.44}{2.3} = 4.1$ in.

$b_i = (2 \times 81.4)^{1/2} = 12.75$ in.

$a_i = \frac{12.75}{2} = 6.37$ in.

EXPRESSIONS FOR THE MEAN TURN OF IRON AND COPPER

The mean turn of the iron or copper elements is that quantity which, multiplied by its sectional area, gives its total volume. The mean turn of iron for the shell type is, —

$l_i = 2(a_c$ [illegible] $+ 0.828\, a_i)$ ...... (13)

*Mr. Charles Fortescue was one of the first to express the dimensions of a transformer in terms of these variables.

Where a_c, b_c and a_i are the dimensions of the circuits as shown in Fig. 2. Assuming that the corners of the magnetic circuit are cut off at an angle of 45 degrees, tangent to a radius of $\frac{a_i}{2}$, the constant 0.828 is determined as follows,—

From Fig. 2

$$h = \frac{a_i}{2} \cos 45 \text{ degrees}$$

$$\frac{h'}{2} = \frac{a_i}{2} - \frac{a_i}{2} \cos 45 \text{ degrees}$$

or,

$$h' = 0.586 \frac{a_i}{2}$$

$$\text{Area of one corner} = \left(\frac{a_i}{2}\right)^2 - \frac{1}{2}\left(0.586 \frac{a_i}{2}\right)^2$$

This expression divided by $\frac{a_i}{2}$ gives,—

$$\text{Mean turn of corner} = \frac{0.828\, a_i}{2}$$

And the total mean turn is therefore that given by equation (1).

If the corners of the copper circuit are rounded with a radius of a_c, as shown in Fig. 2,—

$$l_c = 2\left(a_i + b_i + \frac{\pi}{2} a_c\right) = 2\,(a_i + b_i + 1.57\, a_c)$$

In the expression for the mean turn of iron for the shell type, equation (1), replace $\frac{a_i}{2}$ by a_i, which gives for the mean turn of the core type,—

$l_i = 2(a_c + b_c + 1.656\, a_i)$

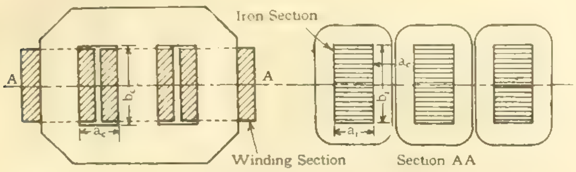


FIG. 3 CORE TYPE THREE PHASE TRANSFORMER

With a section through the winding at right angles to the magnetic circuit.

In case the corners of the windings are rounded with a radius of $\frac{a_c}{2}$, as shown in Fig. 1—

$$l_c = 2\left(a_i + b_i + \frac{\pi}{4} a_c\right) = 2\,(a_i + b_i + 0.785\, a_c)$$

For convenience in the algebraic work following, the mean turn of iron and copper may be expressed in general terms as follows, applying to either the shell or core type,—

$$l_i = 2(a_c + b_c + c' a_i) \qquad (14)$$

$$l_c = 2(a_i + b_i + c a_c) \qquad (15)$$

Where c' and c are constants which have the following values,—

	c'	c
Shell type	*0.828*	*1.57*
Core type	*1.656*	*0.785*

GENERAL EXPRESSIONS FOR THE WEIGHTS OF IRON AND COPPER

From the mean turn expressions given by equations (14) and (15), the weights of iron and copper are as follows,—

$$G_i = 2\, D_i\, S_i\, A_i\, (a_c + b_c + c' a_i) \qquad (16)$$

$$G_c = 2\, D_c\, S_c\, A_c\, (a_i + b_i + c a_c) \qquad (17)$$

Where D_i is the number of pounds per cubic inch of the magnetic circuit, S_i, the space factor of the iron, A_i the gross area of the iron section, and D_c, S_c and A_c the corresponding quantities for the copper circuit. For sheet steel as in curve Fig. 1, sec. III,* $D_i = 0.244$, and the pounds per cubic inch of copper, $D_c = 0.321$.

Example: What are the weights and costs of iron and copper, and the iron and copper losses for the shell type transformer covered by the preceding examples?

From equations (16) and (17), the weights of iron and copper are,—

$$G_i = 2 \times 0.244 \times 81.4\,(4.1 + 9.44 + 0.828 \times 6.37) = 748 \text{ lbs.}$$

$$G_c = 2 \times 0.321 \times 0.4 \times 38.7\,(6.37 + 12.75 + 1.57 \times 4.1) = 254 \text{ lbs.}$$

A density of 12 000 gausses gives from the curve in Fig. 1, Sect. III, a value for the watts per pound W_i of 1.58. A current density of 1550 amperes per square inch at 75°C. gives from equations 3 and 4, Sect. II, a loss per pound W_c of 6.21. The iron and copper losses therefore are,—

$L_i = 1.58 \times 748 = 1182$ watts.

$L_c = 6.21 \times 254 = 1580$ watts.

$L_i + L_c = 1182 + 1580 = 2762$ watts.

The cost of active material based on 15 cents per pound of iron and 45 cents per pound of copper in the transformer, are,—

$C_i = 0.15 \times 748 = \$112.20$

$C_c = 0.45 \times 254 = \$114.30$

$C_i + C_c = 112.2 + 114.3 = \$226.50$

TABLE I—TABULATED TRANSFORMER DESIGN

	Shell Type Single-Phase	Core Type Single-Phase	Core Type Three-Phase
P — K.v.a.	200	200	200
f —Cycles per sec.	60	60	60
I_d —Amp. per sq. in.	1550	1550	1550
B Gausses	12000	12000	12000
S_i —	1.0	1.0	1.0
S_c	0.4	0.4	0.36
N	3150	3150	4620
X^2	2.1	1.0	0.4
Y^2	2.3	2.3	2.7
Z^2	2	2	2
A_i sq. in.	81.4	56.2	43
A_c sq. in.	38.7	56.2	53.7
b_c in.	9.44	11.37	11.5
a_c in.	4.1	4.94	4.25
b_i in.	12.75	10.6	9.3
a_i in.	6.37	5.3	4.65
G_i lbs.	748	705	800
G_c lbs.	254	285	322
L_i watts	1182	1115	1270
L_c watts	1580	1770	2010
L_i+L_c watts	2762	2885	3280
C_i dollars	112.2	106	120
C_c dollars	114.3	128	145
C_i+C_c dollars	226.5	234	265

Example:—Suppose it is desired to design a core type transformer, based upon the same assumptions as the preceding examples for the shell type, except the value of X^2 which is 1.0.

These two designs for the shell and core types are tabulated in Table I, showing the detailed relations between them. These designs are not necessarily the best possible or even practical ones, but are given only to illustrate the plan of design outlined, which is based upon certain assumptions.

THREE-PHASE TRANSFORMERS

Since in a three-phase, core-type transformer there are two openings in the iron, as in Fig. 3, instead of one for the single-phase, equation 1 must be written,—

$$N = 2\, A_i\, A_c = \frac{9.32 \times 10^9 \times P}{B\, I_d\, S_i\, S_c\, f} \qquad (18)$$

For the same reason,—

$$X^2 = \frac{A_i}{2\, A_c} \qquad (19)$$

Equation 8 then becomes,—

$$A_c = \frac{N}{2\, A_i} \qquad (20)$$

*See the JOURNAL for Sept. 1917, p. 357.

The mean turn of iron for the three-phase transformer equals,—

$$2\ (2\ a_c + 1.5\ b_c + 2.05\ a_1) \quad \text{.......................} \quad (21)$$

The weight of iron equals,—

$$2\ D_i\ S_i\ A_i\ (2\ a_c + 1.5\ b_c + 2.05\ a_1) \quad \text{.................} \quad (22)$$

The weight of copper equals,—

$$2 \times 1.5 \times D_c\ S_c\ A_c\ (a_1 + b_1 + 0.785\ a_c) \quad \text{...........} \quad (23)$$

Example:—Design a 200 k.v.a., 2300 to 230 volt, 60 cycle, three-phase transformer which has the following constants,—$B = 12000$; $l_a = 1550$; $S_c = 0.36$; $S_1 = 1.0$; $X^2 = 0.4$; $Y^2 = 2.7$; $Z^2 = 2$.

The Twin Armature Motors

For the Chicago, Milwaukee & St. Paul Direct-Current Locomotives

Gerald F. Smith

THE ten 266 ton Baldwin-Westinghouse electric locomotives which are now being built for operation over the Rocky Mountain Division of the Chicago, Milwaukee & St. Paul Railroad will be the most powerful locomotives in passenger service, and as they will be supplied almost exclusively with hydroelectric power, they form an important item in the coal conservation program in the far West. Six main motors of the twin armature quill geared type are used per locomotive. This type of motor permits of the development of greater horse-power per axle than any other type in which a single motor mounted between wheel flanges drives a single axle. Each armature is wound for 750 volts, and the twin armatures are connected permanently in series, giving 1500 volts per motor. The motors are insulated for operating two in series on a 3000 volt trolley line.

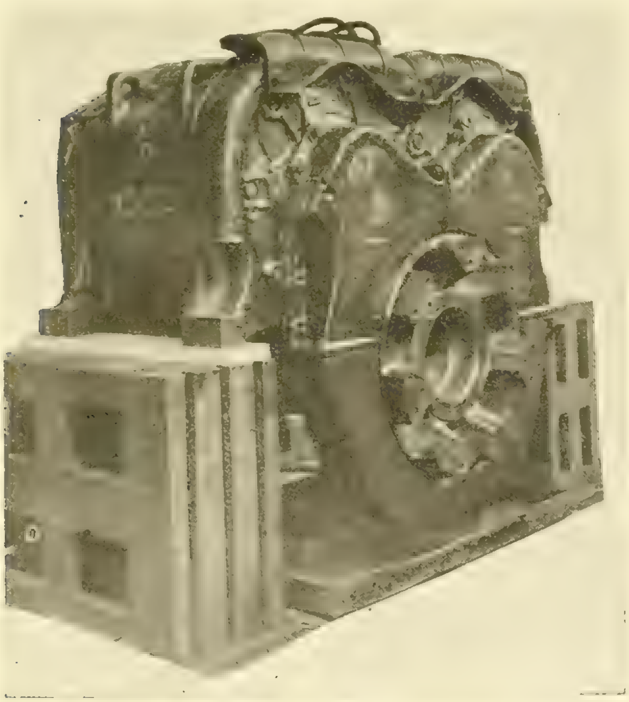


FIG. 1—MAIN MOTOR OF THE CHICAGO, MILWAUKEE & ST. PAUL LOCOMOTIVES

Assembled complete with quill and gear covers.

The contract ratings based on 75 degrees rise by thermometer are 667 hp for one hour, natural ventilation, with all covers off and 533 hp continuously with 3350 cu. ft. of air per minute, forced ventilation. Tests on the first motor manufactured indicate that these ratings are quite conservative. Air for ventilation is supplied by an external blower assisted by a large fan mounted on the pinion end of each armature. These fans greatly assist in distributing the air and draw sufficient cooling air through the motor to allow the auxiliary blower to be shut down when operating over the lighter grades, and thus save power. The cooling air enters a duct through an air inlet placed in the center of the top of the motor. It moves forward in this duct toward the commutator end, where it is blown into the interior of the motor. It then passes in parallel streams through the armature cores, through the air-gaps and through the spaces between the field coils, enters the fan at the rear, and is thrown out through circumferential openings in the pinion end of the frame. These openings are protected by special covers designed to keep out snow and water. The weight of the motor complete with pinions, gear, gear case, quill bearings, quill and quill drive details is 25 400 pounds.

FIG. 2—MAIN MOTOR WITHOUT GEAR CASE OR QUILL

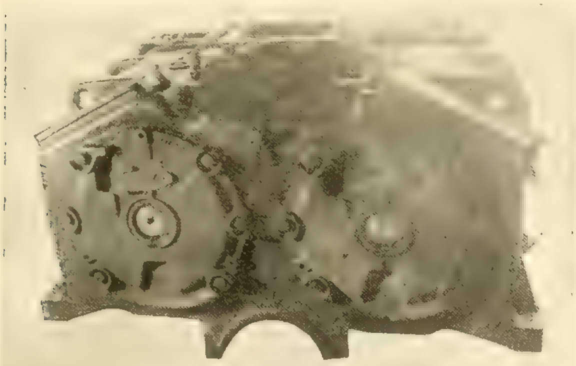
Showing the pinions of the twin armatures.

The motors are mounted on top of the truck transoms of the locomotive, which puts them well up above the road-bed away from the dust, dirt, water and road-bed obstruction. Furthermore, being entirely spring supported, the motors are not subject to the direct shocks or vibrations due to irregularities in the track.

The frame of the motor consists of a rugged steel casting as shown in Fig. 4. Heretofore, twin armature motors of the alternating-current type, adapted for quill drive, had two separate frames which were bolted together. With the direct-current motor requiring a heavy magnetic frame, a saving in weight and cost is

possible by making the frame casting in one piece. The center wall inside the frame does not carry any of the main pole flux and serves only as a supporting wall for the poles and coils, and as a path for the commutating pole flux; hence, it can be made of relatively thin section.

There are four main and four commutating field poles and coils per armature. The field coils are wound with copper straps insulated between turns with asbestos. The insulation around the field coils is of mica with a final taping of heavy cotton tape. The coils are impregnated by the vacuum process with a heat conducting and water proofing compound. The commutating coils are insulated for line voltage. The main



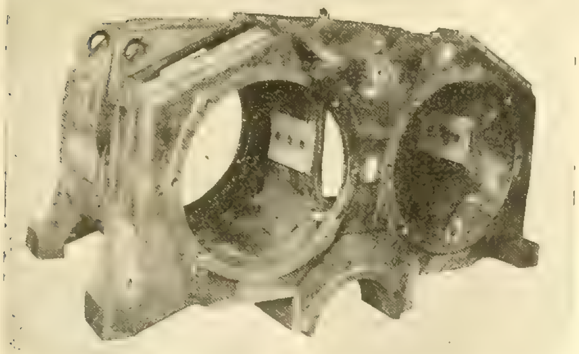


FIG. 3—COMMUTATOR END OF MOTOR
Showing the air in-take.

FIG. 4—STEEL CASTING OF MOTOR FRAME
The main poles on the center wall are of opposite polarity, so that no main pole flux passes through the frame at this point.

coils are always on the ground side and are insulated for one-half line voltage. The field coils are supported between the pole tips and machined surfaces in the frame. They are protected by means of coil shields and washers, and prevented from moving by a heavy spring placed between the top washer and the frame.

The housings which carry the bearings fit tightly into the machined bores in the ends of the frame. They are secured by bolts which are prevented from turning by plate-lock-washers. The bearings are of ample size. They are lubricated by the oil and waste method which is standard for railway motor practice.

There are four brushholders for each armature, each carrying three brushes. The brushholder support consists of a block into which are pressed insulated pins. The insulation is a composition which is moulded on the pins and machined to exact size to obtain a good fit in the blocks. The portion of the insulated pin extending from the block is surrounded by two porcelain bushings in series which gives a long creepage surface to ground. The outer ends of the pins are drilled and tapped axially for bolting to machined surfaces on the frame.

The brushholder is of standard railway motor construction and is bolted to the insulating supporting block. The connections to the brushholders are so arranged that the brushholder or support may be removed with a minimum of disturbance of the connection. This fact, together with the location of the motors up from the road-bed, makes the brushholders convenient for repairing and inspecting. Two openings in the bottom of the frame, two in the corners at the top and one in the center at the top are provided for inspection and removal of brushholders. Six of the brushholders

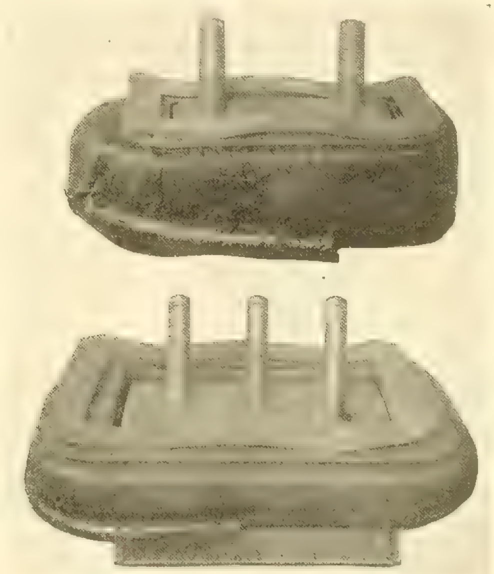


FIG. 5—MAIN AND COMMUTATING FIELD POLES, SHIELDS, WASHERS AND SPRINGS

can be inspected and the carbons removed from the top. The other two are accessible from the bottom. It is not necessary to run the locomotive over a pit in order to inspect or remove brushholders.

The armature is of the standard railway motor type. The shaft is of forged steel and is pressed into the spider. It can be removed for replacement without disturbing the remainder of the armature. The spider and pinion end bell form an integral casting. Figure 6 shows the armature core with commutator in place, and also the large fan on the rear end. Balancing pockets are arranged in the spider, in the commutator end bell and in the fan. The armature core is balanced before the commutator or fan is applied. The commutator is finished all over and hence is not subject to very great variation. The fan is balanced independently before being applied to the core.

The armature coil shown in Fig. 8 is made in one piece and is completely insulated before being applied to the armature core. The complete coil consists of five

single coils each having a single turn of two straps in parallel. There are no cross-overs inside the coil. The coils are insulated with mica with a final taping of strong cotton tape. The complete armature is dipped in insulating varnish and baked several times after being wound.

In Fig. 7 is shown the quill with gear center and gear rim. The gear rim has 89 teeth, each pinion has 24 teeth, and the gear face is six inches wide. By using twin armatures with the two pinions meshing with the single gear, considerable space is saved in the direction of length. There is also no necessity for using the flexible type of gear to insure proper division of load between pinions. At the same time, all the advantages of flexibility of drive are obtained due to the use of the quill springs connecting the quill to the wheels.

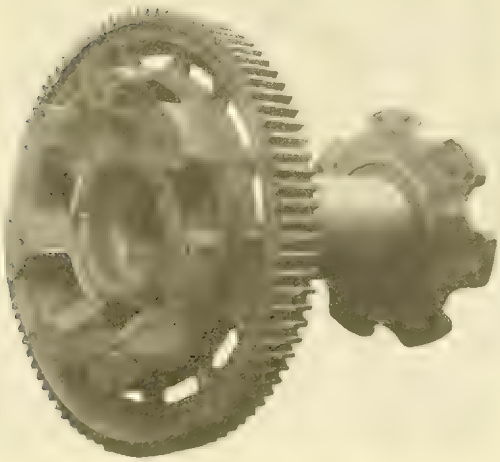


FIG. 6—ARMATURE CORE

FIG. 7—QUILL WITH GEAR CENTER AND GEAR RIM

The upper and lower portions of the gear case are shown in Fig. 9. The upper portion is made of two rugged castings as shown. The line of split between the upper and lower portions of the gear case is 3.5 in. from the horizontal center line of quill. On the pinion end housings, there are skirts extending down to the line of split, as shown in Fig. 2. On the faces of the pinion end housings are flanges to which the upper castings are bolted. The lower portion of the gear case is of sheet steel riveted and welded. It is supported at the ends from the upper castings. Hand holes with spring covers are provided in the upper portion of the gear case. Tongue and groove fits are provided between the gear case and quill, and between the upper and lower portion of the case. It will thus be seen that the gear case is of simple and sturdy construction. The normal clearance between the lowest part of the gear case and the rail is seven inches.

FIG. 8—ARMATURE COIL

The commutating and flashing characteristics of the motor are inherently good, due to the use of only 750 volts per armature. There are 205 commutator bars on each armature, which is ample for 750 volts. The air-gap is proportioned in accordance with the latest practice to give a steep speed curve, so that it is only necessary to shunt one-third of the field current to obtain the maximum speed desired with a full tonnage train on level track. The range of speed at full voltage is from 23 to 65 miles per hour, depending on the load.

In general it will be seen that this motor is of simple and rugged design. The insulation is capable of standing high temperatures and, with the large creepage distances, is liberal for the high line voltage. An ample number of commutator bars are used on each armature, which will greatly reduce troubles from flashing. The capacity is ample for the duty required. The motors can therefore be expected to operate with a high degree of reliability in service.

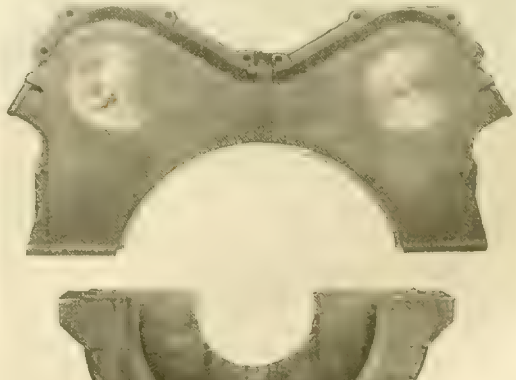


FIG. 9—GEAR CASE

Industrial Controllers-XXII

Locomotives for Mines and General Industrial Purposes

H. D. James & H. H. Johnston

THE electric locomotive is a very important means of conserving the man power so badly needed in our mines and industrial establishments at the present time. One man with a mule can handle a very small tonnage per day, compared with that which the engines and afterwards compressed air locomotives were tried out. The most recent development is the use of electric locomotives, both for the main haulage and for gathering purposes. During the last few years rapid strides have been made in substituting electric lo-

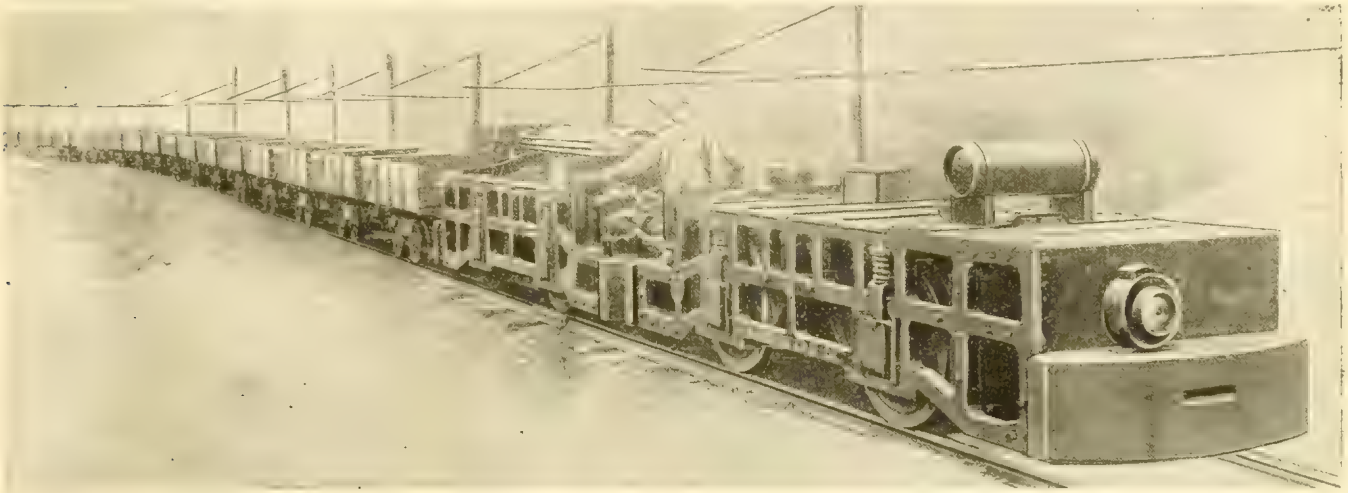


FIG. 1—30 TON TANDEM MINE LOCOMOTIVE MADE UP OF TWO 15 TON UNITS

same man can haul using an electric locomotive. Although the extra cost of the electrical equipment is considerable, it can usually be recovered in a short time where the tonnage is sufficient. The electric locomotive not only reduces the expense of hauling, but increases the efficiency of a mine or industrial establishment by comotives for mules where any considerable tonnage is taken out.

This same development has taken place in industrial establishments. Formerly, the material was trucked from one place to another by man power. This is being rapidly superseded by the automobile truck and storage battery locomotives.

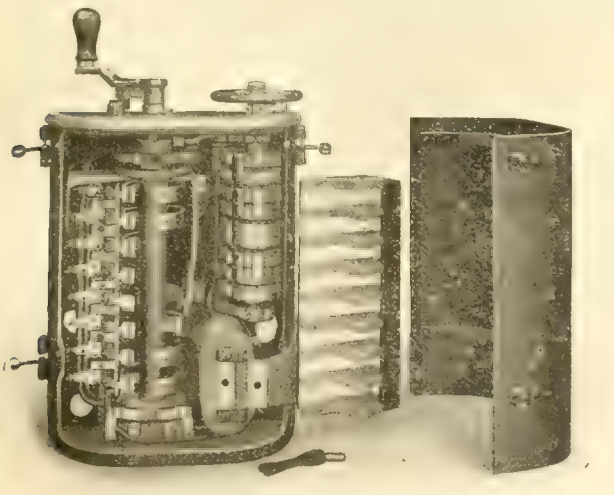


FIG. 2—DRUM CONTROLLER

Showing separate drum for reversing and series or parallel connections.

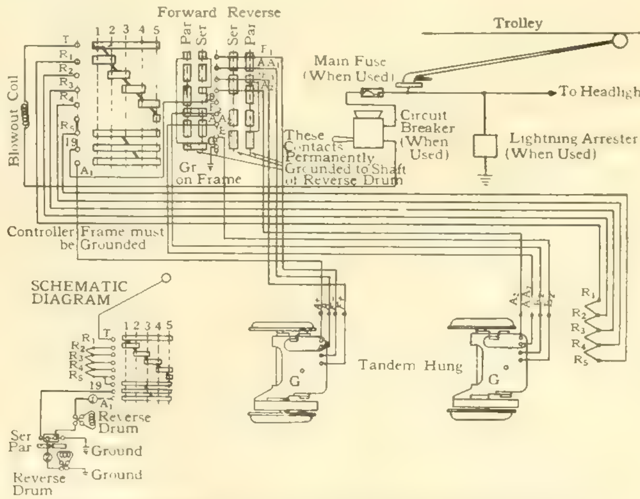


FIG 3 DIAGRAM OF DRUM CONTROLLER SHOWN IN FIG. 2

the speed with which coal or finished material can be moved out of the way of workmen and new material brought to them.

When coal mining operations extended only a few hundred feet, the coal cars were hauled out to the shaft or entry, by mules. As a mine was extended, gasoline

At first, the mining operations were taken care of by one type of locomotive, which was used for hauling the cars through the main tunnel. As the mines became developed, and larger areas were worked, a new class of locomotive was developed for gathering the cars from the side rooms. With this development, larger and more powerful haulage locomotives were built

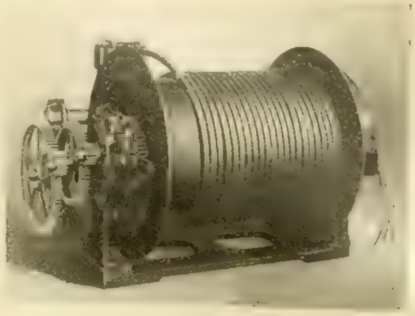
which increased the size of the control apparatus and in many cases, the manual controller has been superseded by remote control.

Electric locomotives for mine and industrial service may be divided as follows:

1—Trolley type locomotives for main haulage.
2—Trolley type locomotives for gathering service.
3—Storage battery locomotives.
4—Combined storage battery and trolley locomotives.

The trolley locomotive is particularly well adapted for high speed, long hauls and heavy grades. It may employ a single trolley wire or third rail and use a bonded track for the return circuit. The single trolley is the usual practice in mines. In some industrial establishments, a double trolley or double third rail is used, in which case the track is not used to form part of the electric circuit and need not be bonded.

FIG. 4—TRACTION REEL GATHERING LOCOMOTIVE



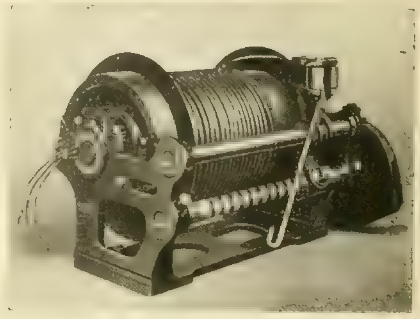


FIG. 5—MOTOR OPERATED CONDUCTOR CABLE REEL

The trolley locomotive for gathering service is employed only in mining operations. In addition to the usual locomotive equipment it may have a traction reel or a cable reel. The traction reel gathering locomotive is equipped with a motor driven reel on which is wound a steel cable. The locomotive remains on the main haulage track and the cable extends into the room or entry and is connected to the cars. The motor operating the reel draws the cars out to the main track so that the locomotive can couple to them. The reel motor is controlled by a simple rheostatic reversing drum controller.

Where the gathering reel is of the conductor cable type, Fig. 5, it may be mechanically driven from the axle or equipped with an individual motor. The conductor cable enables the locomotive to run on a room track for hauling the cars to and from the room working face. Where the electric cable is single conductor, the room track must be bonded. In many cases double conductor cable is used to avoid bonding these tracks. Where the reel is motor driven, an electric motor is built inside of the reel drum and is self contained with the reel. The motor is connected across the power lines with a resistance in series. As the cable is wound off the reel, the motor is driven against its torque and keeps the cable taut. As the locomotive returns, the motor winds the cable on the reel. The action of the motor is thus equivalent to a spring. The torque, however, remains constant and does not vary as in the case of a mechanical spring. The cable passes through a guide driven by the reel which moves back and forth and causes it to wind uniformly across the face of the

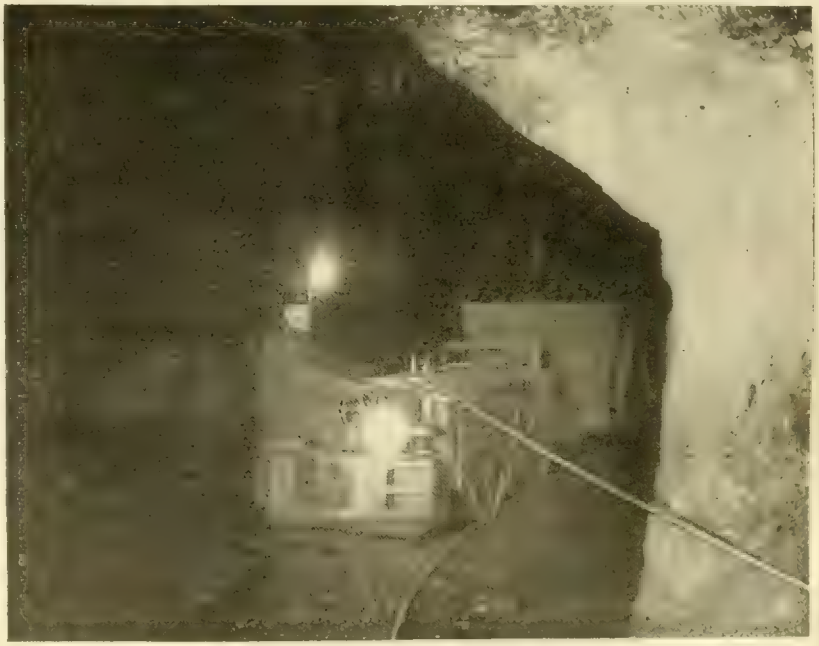


FIG. 6—CONDUCTOR CABLE REEL LOCOMOTIVE

reel. Fig. 7 shows a diagram of electrical connections for the motor driven reel and its control circuit.

The controllers used on all but the very large locomotives are manually operated, usually the drum type. Each controller is provided with two handles:—the operating handle controls the speed of the locomotive; the other handle makes the proper connections for forward or reverse operation, and where two or more motors are used, it provides for either series or parallel con-

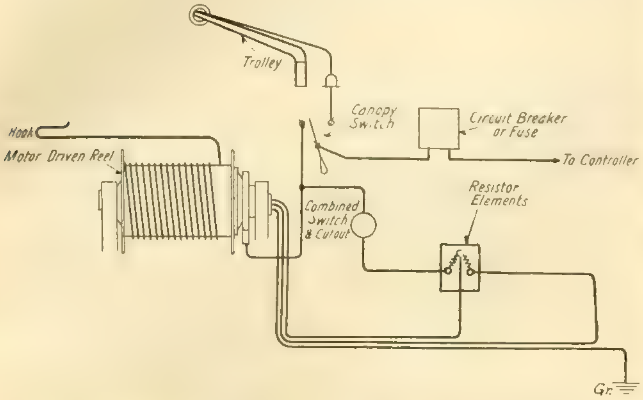


FIG. 7—DIAGRAM OF MOTOR OPERATED CONDUCTOR CABLE REEL

nections. The handles are interlocked so that the direction of rotation and series or parallel connections cannot be changed unless the operating handle is in the off position. Controllers for mine locomotives must be made short in the vertical direction and as flat as possible, as the overall dimensions of the locomotive are very limited in mining work. Controllers for industrial locomotives need not meet these requirements.

Each locomotive usually has two or more motors which can be connected in series or in parallel. Fig. 3 shows the diagram of connections for a drum controller arranged for two motors. The drum connected to the operating handle is shown at the left of the main diagram and at the top of the schematic diagram. It connects the motors to the trolley circuit through a resistance which is short-circuited in five steps. To the right is the forward, reverse and series parallel drum. These connections can be changed only when the drum shown

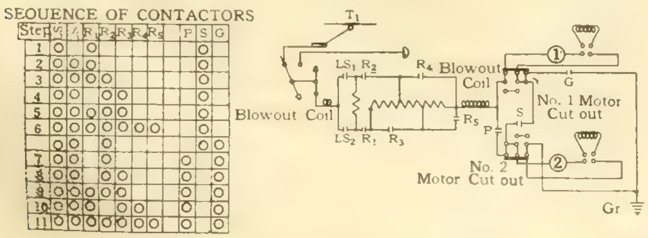


FIG. 8 DIAGRAM OF CONTACTOR CONTROL

on the left is in the off position, the interlock consisting of a mechanical connection between the handles on the inside of the controller.

Larger locomotives are equipped with air brakes and contactor control. The operating handle provides for both series and parallel connections. A separate handle sets the circuit for either forward or reverse operation. Fig. 8 illustrates a typical controller for this type arranged for two motors. These locomotives are sometimes quite large and are often used for handling several freight cars at one time.

A pusher locomotive differs from the regular locomotive by the addition of a bar which projects from the side of the locomotive and enables it to move the cars on an adjacent track, as illustrated in Fig. 9.

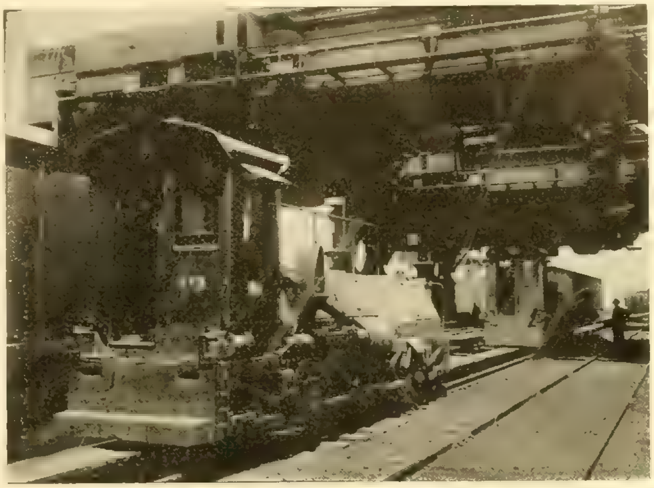


FIG. 9 PUSHER TYPE LOCOMOTIVE WITH THIRD RAIL

On the Cleveland Ore Dock of the Pennsylvania Lines. This locomotive runs on tracks parallel to those of the cars, and pushes the cars with a pneumatically operated arm.

It is often difficult for a locomotive operator to "spot" cars properly where the train is of any considerable length. It is possible to improve these conditions, by erecting a tower adjacent to the track and arranging the control so that the locomotive operator can leave the cab and operate his locomotive from the tower. Contactor control with master switches are used and a control wire is run from the locomotive to the tower by means of an additional trolley or third rail.

Where a considerable tractive effort is required and the size of rail or operating conditions will not permit the use of a single locomotive, the locomotive is divided into two parts and is known as a tandem locomotive, Fig. 1. One of the units is a leading or primary unit and the other a secondary unit. The primary unit is equipped with a four motor controller to control two

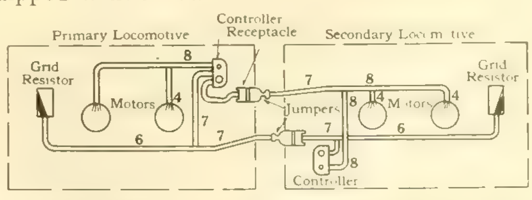


FIG. 10—ARRANGEMENT OF BUS LINE RECEPTACLES FOR TANDEM LOCOMOTIVE

motors on each unit. The electrical connections between the two units are made with jumpers, each locomotive being equipped with its own resistor. The two units are operated electrically in parallel, the motors on each unit being connected in series or in parallel in the customary way, and the resistors on the two units being paralleled step to step by the controller contacts on both the series and parallel connections of the motors. When operated separately the connections on the primary unit

which are provided for the motors and resistor of the second unit remain idle.

Where the locomotive is equipped with air brakes and remote control, arrangement can be made for connecting several of these units together and operating as a single locomotive. A good illustration of this is three 25-ton locomotives recently installed by a large copper company. Each of these locomotives can be

FIG. 11—STORAGE BATTERY LOCOMOTIVES IN AN INDUSTRIAL PLANT

operated as a single unit or the three units can be connected together, giving the equivalent of a 75 ton locomotive with a distributed weight, so that no heavier track is required than for the single 25 ton unit.

The storage battery locomotive, Figs. 11 and 12, is usually designed for slow speeds of about 3.5 miles an hour. It is particularly adapted for short hauls and intermittent service. Heavy grades and high speeds cause a very high discharge rate on the battery, which makes the size of the battery out of proportion to the service rendered. These locomotives are operated in shifts to allow time for charging the battery. Sometimes extra batteries are provided to keep the locomotives in continuous service, the idle battery being charged while the other battery is in service on the locomotive. Storage battery locomotives are particularly well adapted for industrial purposes where a trolley wire or third rail would be objectionable. The loading and unloading of cars consumes time and a great deal of the work consists in shifting cars from one place to another, and in most industrial plants few if any

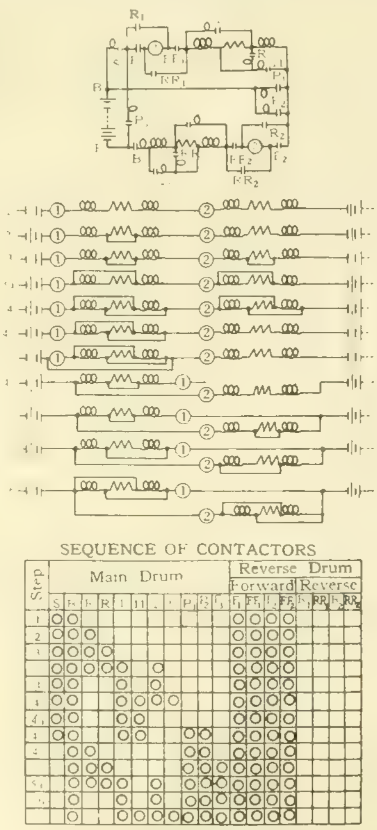


FIG. 12—DIAGRAM OF A TWO MOTOR STORAGE BATTERY CONTROL

grades are encountered. These locomotives are also well adapted for gathering service in mines. The volts per cell for commercial storage batteries is quite low so that motors are wound for considerably less voltage than is common for power service. This increases the

FIG. 13—COMBINED TROLLEY AND STORAGE BATTERY LOCOMOTIVE

With cover removed showing location of the motors and storage battery.

current per horse-power considerably and makes it necessary to use larger contacts for a given horse-power. For a single motor, the controller consists of an ordinary drum with rheostatic control. The forward and reverse connections are made on a separate drum, the change in connections being made when the operating handle is in the off position.

Where two or more motors are used, the motor armatures and fields are combined in series and parallel relations which gives a wide range of speed with very little rheostatic loss and conserves the energy in the storage battery. Fig. 12 is a schematic diagram

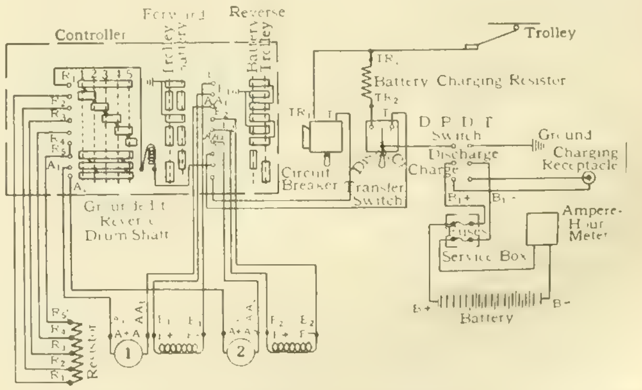


FIG. 14—DIAGRAM OF CONTROLLER FOR COMBINED TROLLEY AND STORAGE BATTERY LOCOMOTIVE

showing such an arrangement. The numerals *1* and *2* represent the two motors. Each motor is provided with a double field winding. The motors are first connected with their armatures and all of their field windings in series. This gives a maximum field strength and maximum torque with a relatively small current. After the starting resistance has been short-circuited, the field windings are connected in parallel, giving a higher speed by field control. Higher speeds are obtained by changing the armatures from series to parallel connec-

tions. Six operating speeds are shown on this diagram. The steps marked with sub letters, such as *3a*, *4a*, etc. are transition steps and not intended for running positions.

Sometimes, the locomotive is designed for operation both from a storage battery and a trolley, the battery being used for short hauls where it is not convenient to provide the trolley wire, such as for gathering purposes in a mine. Fig. 13 shows such a locomotive and Fig. 14 a diagram of connections. The operating handle provides ordinary rheostatic control. The separate handle which can be moved only when the operating drum is in the off position provides for connections for either forward or reverse operation on either the trolley or battery. A locomotive of this kind has considerable flexibility, but the added weight of the battery is a disadvantage in operating on the trolley wire. Some quite large industrial locomotives of this kind are employed by a large plant where it is necessary to haul cars across property where a trolley cannot be installed. In such cases, the battery can be charged, if desired, while the locomotive is operating from the trolley.

Dad, the Inspector, on Motor Maintenance

L. J. Davis
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Detroit, Mich.

"DAD", said helper Jack, as they lit their pipes after drinking the last of the coffee from their dinner pails, "I see the old man fussin' around the armature room a lot these days and heard him talkin' somethin' about dippin' an bakin' armatures. What kind of a crazy noshun has he got in his head now? Don't them armatures git baked enough already? The one we took out of that motor today was sure well done."

"That ain't the idee a tall, son, and let me give you a little tip. Don't git into the habit o' thinkin' that everything new the old man starts is a crazy noshun. I remember we all thought he was ready for the wagon when he bought some new motors that had solid kettles instead o' split, and had four little fields besides the four regular big fields. We figgered we'd be pumpin' them jacks all the time liftin' cars so as to get out motors, but we don't take out half the armatures we used to, and besides they is a lot o' work gets done on them trucks when we do take out a motor that would never git done till she broke down if we was usin' split kittles."

"It certainly is a lot more work to take the fields out of a motor that has four big ones and four little ones, but the fields nowadays is taped better, and has some sort of a gum run into 'em that keeps 'em from shrinkin' so much and keeps out the water. Them stiff springs under the fields keeps 'em up tight against the poles so they don't git loose and rub through the tape and ground near so often as the old kind did. Since then I figger that the old man knows pretty near what he's doin' before he goes ahead."

"Now from what he says to me, I figger he's got the same idee about armatures. You see when a armature runs a year or so the tape and that stuff on the coils gits dried out and the coils gits loose in the slots and ev'ry time the motorman speeds up the car them coils tries to fly out of the slots, and when he slows down they flop back again. When they do this they rub on the sides of the slots and on theirselves where they cross at the ends and git grounded and short and break off at the commutator."

"If they was springs alongside the coils in the slots they would help take up this play and hold them coils but nobody ain't done that yet, so the old man figgered he'll hold them coils where they belong by fillin' in all around 'em and inside 'em with varnish and bakin' this varnish hard enough to hold 'em. They can't no dirt nor water get into them coils neither, cause they will be all sealed up with this here varnish."

"He tells me that he is goin' to take out all them armatures and heat 'em up and put on new bands, and then heat 'em and dip 'em in this here varnish and hang 'em up to dreen and then bake 'em till the varnish is solid. That's what he's buildin' that tank and oven for."

"But say, Dad, ain't that goin' to be an awful lot o' work?"

"Sure it is, son, but them motors has run two or three years now and they need goin' over, and the dippin' and bakin' ain't goin' to be much more work when we git that new outfit. Another thing, Jack, me and you has got to keep these cars runnin' this winter cause they ain't no guys that knows anything about motors around lookin' for a job and I'm shy two men now. The old man says after he gets these motors dipped and baked that me and you can take care of 'em easy and we won't have so much luggin' to do, neither.

"Did you ever stop to figger that this traction company has got only one thing to sell and that is rides, and people can't ride on cars that is settin' in the shop, and my pay and yours comes out of the money them people pays for ridin'? Anything that keeps them cars ont' the road helps you and me, Jack."

"But Shultz was sayin', Dad, that he bet the old man was gettin' up some scheme to do away with more men, and if he kept on we'd all be out of a job."

"Boy, that's the same old argument some guys put up when Joseph had Hoover's job under old man Pharaoh, and wanted to use a jackass to pull a plow instead of a man. They ain't half enough man savin' machinery in this shop nor no other shop in the country, but they is going to be more, boy, they is going to be lots more. If Shultz wants to let the jackass chaw thistles and rest and watch Shultz work, let him go ahead, but you figger on gittin' the jackass to do all of his kind of work you can so's to leave you loose to do somethin' that takes a man."

"Well, there she blows. Let's get busy."

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

OCTOBER 1918

Winter Operation of Railway Motor Equipments

With the coming of the winter season and the memory of last year's experience still fresh in the minds of railway operators, ways and means of better meeting a repetition of these conditions are being considered with the object of keeping the cars on the road and supplying satisfactory service to the traveling public. A thorough study of existing conditions during the past winter on a number of railway properties throughout the country has emphasized the importance of a few fundamental principles.

SHOP ORGANIZATION

It is of vital importance to have an efficient and well-organized body of trained men to take care of all repairs, under the supervision of a competent master mechanic.

REGULAR INSPECTIONS

In order to catch partial defects in equipments, before they go too far and cripple cars in service, regular and frequent inspections should be made at stated intervals of time or on a mileage basis under the direction of experienced foremen.

MOTOR WINDINGS

Completely wound armatures and field coils that have been thoroughly treated by dipping and baking, using a good grade of baking insulating varnish, have been found to withstand the water and moisture encountered during the winter service with less resultant troubles than untreated windings. This treatment of the windings is highly recommended as a means of reducing trouble due to grounds and short-circuits.

PAINTING INSIDE OF MOTOR FRAMES

Some operators have experienced less trouble due to grounded windings by painting the inside of the motor frame with a heavy asphaltum paint. This should be done after all dirt and grease have been removed from the frame.

MOTOR LEADS

All motor leads should be cleated to prevent rubbing and chafing to insure against broken and grounded leads. A heavy coating of paint protects these leads against snow and water by making them moisture proof.

MOTOR COVERS

Suitable tight fitting solid commutator and hand hole covers should be placed on all non-ventilated motors to prevent snow and wheel wash from getting inside of the frame and damaging the windings and brushholders. Armature and axle bearing oil well covers and all dust shields should be made tight fitting and securely fastened to keep water, dirt and snow from getting into the bearings with resultant bearing troubles.

Motors of the ventilated type that ordinarily operate with perforated covers should be provided with solid covers, wholly or in part for winter service, to keep out the snow and water. The application of solid covers to these motors should to a large extent be controlled by local conditions, such as maximum operating temperatures of motors and the severity of the winter as judged from the average yearly snowfall. In general, where operating temperatures are as low as 55 to 60 degrees rise, solid covers should be applied during the winter months in localties subject to snow. If operating temperatures are high, (75 degrees rise) and snowfall is light, the regular perforated covers should be used all the year round. Where snowfall is heavy, apply solid covers during the winter months, disregarding the motor temperatures.

MOTOR DRAIN HOLES

These holes provided in the bottom of the motor frame casting to allow for the proper drainage of water from the inside of the motor quite often become clogged with dirt, snow or ice. During the regular inspection period, these holes should be cleaned out and openings cleared.

GEAR CASES

Gear cases are subjected to bumps and severe strains due to snow and ice between the rails, and for this reason they should be made to clamp securely to the supporting lugs, by keeping the clamping bolts drawn up tight and securely locked. The two halves should be carefully fitted together to keep out snow and water.

AXLE CAP AND MOTOR FRAME BOLTS

It is very important that all bolts on motors be kept tight and securely locked to prevent parts from working loose, thus allowing water to enter into the motor frame and bearings. These bolts should be carefully gone over and tightened at each regular inspection.

BEARINGS

By giving careful attention to the packing and oiling of bearings, using a clean long fibre wool waste and a good grade of winter car oil, bearing troubles will be reduced to a minimum. A further great saving in maintenance and a reduction in the number of motor failures can be obtained by a careful and regular gauging of armature bearing wear with feeler gauges in the air-gap. Bearings that are worn approximately 1-16 inch should be replaced to prevent the armatures from getting down on the poles and damaging the windings.

CAR WIRING

All unprotected car wiring should be well cleated to prevent rubbing, and painted with a heavy asphaltum paint to keep out the snow and water.

DETAIL APPARATUS

The windings and leads of all detail apparatus should be thoroughly painted with a good grade of asphaltum paint and should be provided with suitable tight fitting covers and guards properly located to protect them from snow and water.

AVAILABLE SPARE PARTS

It has been found by experience that it is good practice to keep in stock an available supply of spare parts of all apparatus and detail parts to meet emergencies. This is especially important at the present time, owing to the long delivery date for spare parts forced upon the manufacturer on account of the conditions of the labor and material markets. It is also well to remember that during these times, shipping facilities are not very reliable and although the material may be available for shipment, its delivery may be delayed.

SNOW FIGHTING APPARATUS

Snow plows, sweepers, ice-scrapers etc., should be examined, put in good working condition and kept ready for service at a moment's notice. Operators who depend on passenger equipment to keep the roads clear of snow and ice have experienced a large number of pull-ins, resulting in a high maintenance and unsatisfactory service to the public.

Cars that are used in bucking snow may do the work without showing any immediate apparent injury to the motors, but it should be definitely understood that the excessive overheating of the motors by this overloading, weakens the insulation of the windings and shortens the life of the equipment. This is especially true in the case of cars equipped with light weight ventilated type motors which have a lower overload rating.

SYSTEMATIC PUBLICITY

A very important consideration which is too often overlooked in connection with the operation of a street railway, especially during the severe winter season, is that of keeping the goodwill of the traveling public. During these months there are a number of existing conditions beyond the control of the operating company, such as—

Extremely severe weather.
Surface drainage with resultant flooding of streets and tracks.
Congested street traffic.
Stranded automobile trucks.
Abnormal labor conditions.
Shortage of coal.

These factors tend to disorganize the transportation department and cripple the regular operation of the cars, arousing the indignation of the public, who are to a large extent ill-advised or ignorant of the facts. By the expenditure of a little printer's ink in the form of posters, private publications or advertisements in the daily newspapers, the truth regarding these conditions can be brought forcibly to the attention of the people, which will result in securing their co-operation rather than their condemnation. J. S. DEAN

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

OCTOBER 1918

Charging of Storage Batteries on Interurban and Street Railway Cars

The application of storage batteries for the operation of such apparatus as the main car control, conductor's signals, passenger buzzer system, governor synchronizing, marker lights, etc., has been handicapped to some extent by certain prejudices apparently due to the difficulty in maintaining the batteries at their proper charge.

In general, the use of a storage battery is only warranted in cases where a sufficient number of auxiliary circuits require power at a low voltage or where the operating conditions permit of the charging of batteries with proper facilities for inspection at road terminals. As a rule, very few operating companies are equipped with the necessary apparatus for charging or inspecting batteries. It is also true that in only a few cases are terminal accommodations available.

CHARGING ARRANGEMENTS

Assuming that the above conditions are true and that it is absolutely essential that a storage battery be used, either of the following schemes can be employed. In choosing one of these charging methods, there are several conditions which either limit or prohibit the use of either scheme.

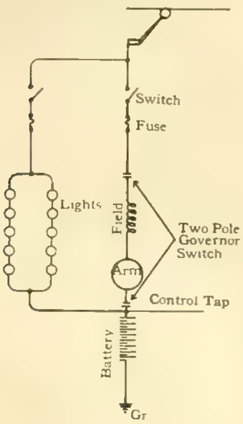


FIG. 1

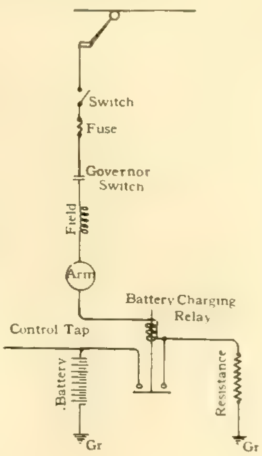


FIG. 2

In Fig. 1 the battery is connected directly in the ground side of the compressor circuit with a double-pole governor switch breaking both sides of the compressor circuit. A hand operated switch with its fuse is connected in the high potential side of the circuit for cutting the compressor out of circuit.

With this method of charging, the battery is cut out of the compressor circuit by means of the double pole governor switch. The use of this switch is made necessary by the possibility of the compressor grounding. Should such a ground occur, it can easily be seen that the battery would soon discharge itself through this ground were it not for the open circuit caused by the double pole switch. The operation of this switch is controlled by the air governor.

This method of charging has two inherently poor characteristics as follows:—

First, when the compressor is running, the voltage will be somewhat higher than it is with the compressor cut out due to the difference in the charging and discharging voltages.

Second, it is necessary for the battery to carry the total current required by the compressor, which in some cases may be higher than is required by the battery for charging. With the Edison battery, this fault is not so serious as it is with a lead battery. Where the compressor current is within the range of the battery, this defect disappears.

The second method of charging, as shown in Fig. 2, does not require the double-pole governor switch, but uses in its place a battery charging relay and a bank of resistance. A single-pole governor switch is used to operate the compressor. The operation of this scheme is as follows:—

When the governor switch closes, the current passes down through the relay series coil and resistance to ground. On becoming energized, the relay coil operates a plunger on which are mounted a pair of contacts. These contacts close the circuit through the battery to ground forming two parallel circuits for the compressor current to ground. The value of the resistance is determined by the compressor current and the total amount of charging required. This charging value is obtained by the amount of power necessary for operation of apparatus for a predetermined length of time relative to the time the compressor is in operation.

As a general rule, the compressor operation can be estimated at a value some where between 35 and 70 percent of the total time the car is in service depending on several variables such as type of service, the condition of the air apparatus and the limit settings of the governor. The over-voltage feature obtained in Fig. 1 is also obtained in this scheme as power is being drawn from the battery during charging.

There is one method for overcoming the disadvantage of high voltage during charging, which requires two batteries instead of one. A set of two double-pole, double-throw battery switches is also required. With this arrangement, however, some such scheme of operation as charging one battery on the even days of the month and the other on the odd days is necessary. It can be seen that with this method of charging, one of the batteries will probably be doing all of the work any way, as the operator may neglect to throw the switches.

The proposition of using two batteries has one distinct advantage over the two schemes as described above and that is the possibility of overcharging a battery is not so great as with one battery connected in the circuit all of the time the compressor is running. Overcharging of an Edison battery, however, is not serious.

The double battery proposition can be used to good advantage on properties where terminal charging facilities are available. Charging by this method usually requires a system of records.

It sometimes happens that the compressor current is insufficient to give the required charge to the battery. Where the difference between the charge and discharge is not very great it has been found possible to obtain the required charge by utilizing the current from the lighting circuits connected in the battery circuit. A few cases have been noted where it has been found advisable to arrange an auxiliary charging resistance of small current capacity to be used for charging over night.

H. R. MEYER

THE ELECTRIC JOURNAL | INDUSTRIAL APPLICATIONS OF ELECTRIC HEATERS | OCTOBER 1918

Small Drying and Baking Ovens

In almost every industry, there is the necessity for the use of one or more ovens for laboratory or experimental work, such as for making tests to determine the best manner of baking lacquers or enamels, for drying samples of ores, ceramics, etc. Usually the conditions under which these experiments are made are such that space is limited and it would be wasteful and expensive to use the large ovens manufactured for commercial use, having oven heaters of standard design and large capacity. Instead, small ovens are used which are usually too small to permit the use of the standard oven heaters.

Usually it is necessary to provide for a greater range of temperatures with small ovens than with larger ones on account of the experimental uses to which they will be put. Of course, the design of the oven depends on its use, the need for ventilation, the amount and kind of material to be heated, the temperature to be maintained, the time in which it is required to heat the material, etc.

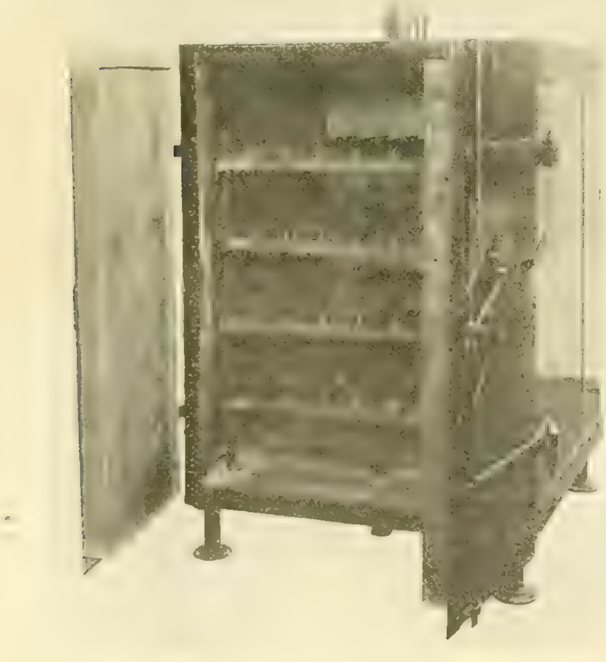


FIG. 1—TYPICAL SMALL DRYING AND BAKING OVEN

An example of a typical small oven for drying and baking samples of ceramics is shown in Fig. 1. It is 18 inches by 18 inches by 18 inches, inside dimensions. It consists of an inner shell of one-thirty-second inch black iron, an outer one of one-thirty-second inch galvanized sheet iron with a three inch space between the two shells filled with thermal insulation. A door occupies the entire front of the oven, and is constructed with an inner and outer wall of thin sheet iron and a three inch space filled with thermal insulation. The door is well constructed so as to leave no cracks when closed for the escape of heat. The entire oven is so constructed as to have strong walls which will not buckle, yet there are no stiffening bolts extending through the oven walls to conduct heat away from the oven interior. A vent is provided in the roof for ventilation, and a hole is provided in one side for the insertion of a thermometer

Four wide type steel-clad heaters are placed on the floor of the oven and four against the roof. Since these heaters are only three-sixteenths inch thick, they take up but little room. Each heater is rated at 190 watts, 110 volts and the oven at 1520 watts, 110 volts. The heating equipment is sufficient to provide oven temperatures of from approximately 300 degrees maximum to 100 degrees C. minimum.

Automatic temperature regulation by means of a thermostat and magnet switch, as illustrated in Fig. 2 is preferable,

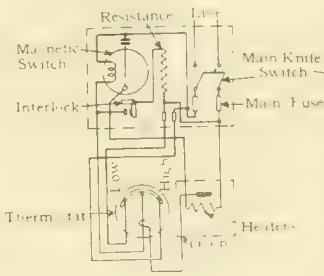


FIG. 2—CONNECTIONS FOR AUTOMATIC CONTROL

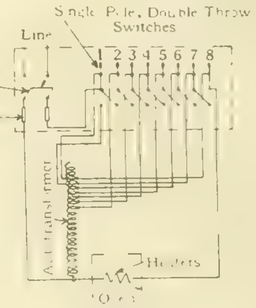


FIG. 3—CONNECTIONS FOR NON-AUTOMATIC CONTROL

since any temperature up to the maximum obtainable can be obtained and automatically maintained simply by setting the thermostat. Since the thermostat cost is appreciable compared with the cost of the oven and the heaters of this type, some non-automatic control is sometimes preferred. The requirements of the oven are such that the maximum rating of 1520 watts permits the use of an auto-transformer type sign lighting economy coil and the switching arrangement shown in Fig. 3 provides a satisfactory temperature control. Table I indicates the approximate inputs obtainable in this typical oven.

TABLE I

Switch Number	1	2	3	4	5	6	7	8	[illegible]
Switch Position	down	.....	.....	.....	.....	.....	.....	up	1840
	up	.....	.....	.....	.....	.....	.....	up	1520
	up	.....	.....	.....	.....	.....	up	down	1250
	down	.....	.....	.....	.....	up	down	down	1230
	up	.....	.....	.....	.....	up	down	down	1020
	down	.....	.....	.....	up	down	down	down	970
	up	.....	.....	.....	up	down	down	down	800
	down	.....	.....	up	down	down	down	down	740
	up	.....	.....	up	down	down	down	down	615
	down	.....	up	down	down	down	down	down	550
	up	.....	up	down	down	down	down	down	450
	down	up	down	down	down	down	down	down	380
	up	up	down	down	down	down	down	down	310
	down	down	down	down	down	down	down	down	240
	up	down	down	down	down	down	down	down	200

R. A. BOLZE

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1643—ALTERNATOR PHENOMENON—I notice that when two similar 12-pole alternators are so located that a line of sight can be had through their fields there is apparently no relative movement of the field coils at synchronous speed. Any slight variation in speed is noticeable by the movement of poles either forward or backwards. I further notice that in shutting down either machine there is the same phenomenon as at synchronous speed, this happening at least three times before the final stopping of the machines. Please explain the reason for the above action and tell what the other speeds are where no movement is noticeable. Will higher speeds give the same results? J.H.B. (WYO.)

This is the same phenomenon that is produced when the wheels of a buggy or automobile are seen through a picket fence. It is most noticeable in a power house when a rotating field alternator is seen at night by the light from an enclosed carbon arc lamp which is fed from the bus-bars to which the alternator is connected. The poles appear to stand still, although the spider appears to be rotating as usual. If several alternators are in parallel and any hunting occurs, the poles which normally appear stationary seem to swing back and forth, making the hunting evident visually. This phenomenon is frequently made use of by the engineer in bringing the alternators to synchronism. This is also the principle that is used in stroboscopic methods of measuring the slip of induction motors. (See article on this subject in the JOURNAL for July 1913, p. 699.) It is produced in the case of the arc lamp by the fact that the light is fluctuating in synchronism with the poles, so that the maximum light occurs always at the same instant that a pole is in a given position. The pole, being seen less clearly in other positions, is apparently seen in only the one position. Hence it apparently stands still. When looking between the poles of one alternator at those of another when the machines are in synchronism the view of the farther poles is cut off from the vision except when they are in certain constant positions. This is independent of the number of poles if the machines are of the same frequency, as the same number of poles pass a given point per second. When the farther machine is slightly below synchronism the intervals at which the poles are seen occur faster than the rotation of the farther poles, hence these poles appear to rotate backward. This same phenomenon occurs with less distinctness when one of the machines is rotating at approximately half synchronous speed, as in this case every other pole is seen or else each pole is seen between every alternate space; and it also occurs with still less distinctness with other even multiple speeds:—as for example ⅔, ⅓, ¾, or ¼ synchronism; or 1⅓, 1½ or 2 times synchronism. In these latter cases the machine appears to be rotating forward when it is slightly above an even fraction of synchronous speed and backward when slightly below the even fraction. C.R.R.

1644—MANUFACTURE OF HYDROGEN—We are about to build a plant for decomposing water to furnish gases for our oxy-hydrogen welding but before doing so are in need of some information. According to Faraday's laws of quantitive electrolysis the following should work out. If one cell with five ohms internal resistance is connected in a ten volt circuit, a current of two amperes should flow through it and this then should liberate 2 times 0.000010352 equals 0.000020704 grams of hydrogen for every second the current is on. Is this correct? Now say five electrolytic cells whose internal resistance is one ohm each are connected in series in a ten volt circuit. A current of two amperes will flow through these five cells and 0.000020704 grams of hydrogen will be liberated in each of these cells for every second the current is on, or 0.000103520 grams of hydrogen would be liberated by the five cells per second. The power required will be the same (20 watts) for one cell as for five cells, will it not? Two of our engineers claim that the five cells will not liberate any more hydrogen than the one unless they have more current and that is not true I believe. F.B.M. (MICH.)

The figures given are essentially correct. The amount of hydrogen evolved will depend on the current per pair of plates. A number of low resistance cells in series will of course produce or evolve more gas than one small high resistance cell carrying the same current. In the latter case the remainder of the energy would go into heat and evaporate the water as well as be lost in radiation. There must of course be a minimum voltage per cell which should not be less than about two volts. This is due to the fact that the dissociation of water requires a certain e.m.f. in addition to the resistance of the electrolyte which produces the same effect as a counter e.m.f. Thus at least 1.5 volts per cell is required to produce any current whatever; and voltage in excess of this produces a much larger increase of current than is proportional to the increase in voltage. In other words in determining the current from the resistance of the circuit, the e.m.f. required to produce dissociation must be subtracted from the applied e.m.f. before using Ohm's law. It is assumed that the above example is to bring out the principles involved rather than actual practice, as much larger currents than stated are required to produce gas on a commercial basis. R.P.J.

1645—FLEXIBLE COUPLING FOR INDUCTION MOTOR—Where the question of starting current is important would the maximum instantaneous starting current be appreciably reduced by connecting a squirrel-cage induction motor to its load by means of a flexible coupling? I have in mind a flexible spring coupling which would permit considerable angular displacement between its two halves. In my opinion energy could be stored up in the spring for a very short interval of time until the point of motion was reached when the spring could assist the motor in producing motion with less current. The total electrical consumption would probably be the same but I am very anxious to get your opinion as to the reduction in the starting current by using a coupling of this type. G.H.M. (ALBERTA)

The maximum instantaneous value of the current would not be affected by the nature of the mechanical connection to the load. The only effect of such a coupling as described would be to change the time for which the maximum value existed. The locked value of the current would be reached in any case but it might decrease at a faster or slower rate depending on the nature of the load, friction, connection to the load, etc. Devices of the kind mentioned are of no practical value so far as relieving the supply circuit during the starting period is concerned. A.M.D.

1646—REVERSING ROTATION—We desire to reverse the direction of rotation of a 15 k.v.a. alternator, as a new engine is being installed, which runs in the opposite direction from the old one. The position of the alternator cannot be changed without rearranging the entire plant. The alternator has a small exciter belted to it. Kindly advise what changes are necessary so that the alternator can be used with the new engine. G.L.H. (ILL.)

If the above generator is a single-phase machine, or if it is a polyphase machine having no polyphase motor load, no change whatever in generator connections is necessary. In case it does supply polyphase motors, a change in connections should be made to avoid reversing the direction of rotation of the connected motors; if three-phase, interchange any two of the generator leads; if two-phase interchange the two leads of either phase. The changed engine rotation will affect the exciter. To make the exciter voltage build up with the reversed direction of rotation and to maintain the correct polarity of the series winding, it would be necessary to interchange the shunt field leads and also the series field leads, or else reverse the exciter armature leads. F.L.M.

1647—COMMUTATING POLES—If a direct-current machine is "floated" on the circuit, becoming motor and generator alternately, said machine having com-

mutating poles connected as usual in series with the armature, would the commutating poles not be worse than useless? H.F.W. (COL.)

Suppose a commutating-pole dynamo has been operating as a generator, and now changes to motor operation or vice versa. This means a reversal in the direction of flow of current through the machine. Since the commutating winding and armature are in series, the magnetomotive force of the commutating coil still opposes that of the armature. The excess of commutating coil over armature ampere-turns, being reversed in direction, sets up a reversed flux across the commutating-pole air-gap; and the electromotive force generated by this flux is reversed. But this reversal is just what is required, since the reactance voltage in the coils undergoing commutation, also has reversed. Hence, the commutating pole is equally effective during generator action and during motor action. For this reason, the commutating-pole machine is just the type to use under such a condition as that named above. The action of a commutating-pole winding must not be confused with that of a series field winding. F.L.M.

1648—COMMUTATION—A 500 k.w., 250 volt direct-current generator is coupled directly to a 720 hp, three-phase, 60 cycle, 2300 volt, 514 r.p.m. synchronous motor. It is desired to run them inverted, but after reversing the series windings on the direct-current machine it runs badly at the brushes and throws fire at loads above 1200 amperes. It ran badly as a generator, but is worse as a motor. The pole pieces are very close together and the neutral points on the commutator are very narrow. At 240 volts on brushes and all resistance cut out of the shunt field, the machine runs at a speed corresponding to 53 cycles and takes 1200 amperes. The air-gaps are about seven-sixteenth inch. Do you not think commutation would be improved by increasing the air-gaps to one-half inch? The machine has no commutating poles nor is there room to put them on. H.F.W. (COL.)

The poorer commutation observed when operating the machine as a motor than when operating it as a generator, is due likely to the flux being less in motor operation and therefore the field weaker. Increasing the air-gap would require an increase in the field strength, and for this reason it would tend to improve the commutation. From the data given above, it would appear that the bad commutation is largely due to the very narrow neutral zone. If this is true, the most effective way to obtain improvement would be to widen the neutral zone. This could be done by cutting a notch in the side of the pole just above the pole tip, or by putting a strong bevel on the edge of the pole, or if the poles are of the cast-in type, by drilling a hole through the pole near to the tip. The manufacturer of the machine should be consulted before any attempt is made to carry out these suggestions. F.L.M.

1649—REVERSAL OF POLARITY—Our new 1000 k.w. turbine gear-driven direct-current generator having commutating poles and compensating windings, has given us some trouble by suddenly reversing when running in multiple with other machines. Is it not true that direct-current generators having compensating windings passing through the pole pieces very near to the armature, are very sensitive to reversals of their polarity by a reversing current from another machine passing through their compensating windings? H.F.W. (COL.)

We understand the writer to mean a sudden change from generator operation to motor operation, instead of a re-

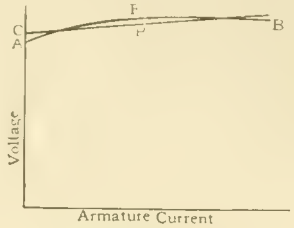


FIG. 1649(a)

versal of polarity at the generator terminals. The action that really occurs is that one or more of the non-compensated machines in parallel with the compensated machine, suddenly changes from generating to motoring, upon a large falling off in load. This is due to the inherent difference in the compounding characteristics of the two types of machines. The compounding curve of the non-compensated machine is not a straight line, but is curved as indicated at *AB*, Fig. (a). On the other hand, the compounding curve of a compensated generator is practically a straight line, as indicated by *CD*. Suppose the load at one moment is such that one machine is operating at the point *E*, and the other at the point *P*. and then the load falls to a low value, the voltage of the non-compensated generator then drops below that of the other, which causes a circulating current between the two machines, increasing the load on the compensated generator and causing the other machine to operate as a motor. Thus, this phenomenon is not due to a sensitiveness in the compensated generator, but is due to its better inherent compounding characteristics. F.L.M.

1650—FIELD DISCHARGE SWITCH—Is it possible to use a two-pole, double-throw reversing switch in the field of a 225 hp motor arranged with discharge clips and connected in such a way that only one discharge resistance is used to absorb the vicious arc that results when the circuit is interrupted, bearing in mind of course, that the motor rotation is changed by this

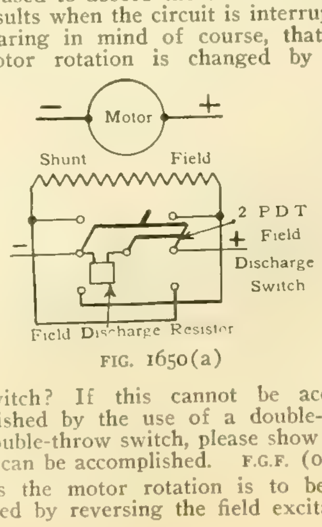


FIG. 1650(a)

switch? If this cannot be accomplished by the use of a double-pole, double-throw switch, please show how it can be accomplished. F.G.F. (OHIO)

As the motor rotation is to be reversed by reversing the field excitation it is assumed that the motor is a shunt-wound direct-current machine. The two pole, double throw field switch with one discharge resistance should be connected as indicated in Fig. (a), which shows only the connections for field reversing without regard to other control connections. It is assumed that a field discharge resistance suitable for the service will be used. L.V.H.

1651—COPPER ZINC SOLDER—In the answer to 1525, a copper-zinc alloy was suggested as a good high melting point solder for use in alternating-current rotor work. Can you advise the composition of this material, also the method of application, whether with blow torch or solder iron? G.B.W. (UTAH)

The copper zinc alloy referred to is probably 50 percent zinc and 50 percent copper, or, in other words, ordinary brazing solder. It is customary to use a flux of borax and on account of the high melting point of the solder, solder iron cannot be used but the work must be done with a blow torch. The flux is dissolved in water and used as a water solution because if it is used as a powder too much is generally used and the excess is difficult to remove from the brazed joint. J.L.J.

1652—RESISTANCE OF METALS—The writer is interested in learning the relative resistance of the following metals:—copper; steel—0.10 to 0.15 percent carbon; steel—0.50 to 0.75 percent carbon; steel—3.5 percent nickel and 0.35 percent carbon. Also how does the resistance of vanadium steels compare with carbon steels? J.B.C. (OHIO)

The resistance of standard copper as adopted by the Bureau of Standards is 1.724 microhms per centimeter cube. Steel containing 0.10 to 0.15 percent carbon will have a resistivity between 11 and 13 microhms per centimeter cube depending upon the nature and amount of other elements present, such as manganese, silicon, etc. Steel with 0.5 to 0.7 percent carbon will have a resistivity between 14 and 16 microhms per centimeter cube depending as above upon the nature and amount of other elements present. Nickel steel with 3.5 percent nickel and 0.35 percent carbon will have a resistivity between 20 and 22 microhms per centimeter cube. The usual commercial vanadium steels contain only fractional percentages of vanadium, and the increase in resistivity due to the vanadium is slight. The values given above are for annealed steels at ordinary temperatures in (20 degrees C.). More exact figures cannot be given, for the resistivity is influenced by impurities and heat treatment. Quenching from a high temperature in general increases the resistivity. The changes will range from three to five percent in low carbon steels, and in high carbon steels may reach more than 100 percent. Tempering lowers the resistance of hardened steels. P.H.B.

1653—TOTALIZING METER—Is it possible without appreciable error to record the total energy in two or more feeders with one watthour meter as shown in Fig. (a)? The motors will vary in size and will not all operate at the same time, the service being intermittent. It is not possible to combine all feeders to a common bus-

bar and use one set of current transformers due to the excessive cost of the wiring. The energy to all motors is supplied from one generating system. One meter to each feeder would require too many meters as there will be about twenty groups.

C.T.P. (CAL.)

This question is answered completely with diagrams by No. 1466. The diagrams in No. 1466 are for single-phase

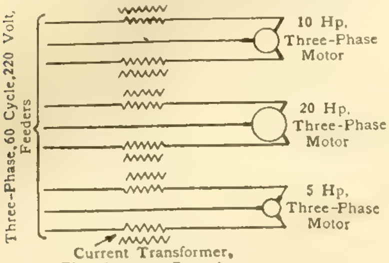


FIG. 1653(a)

circuits but the same principles apply also to polyphase circuits. The most satisfactory scheme is to put current transformers of the same ratio of current transformation in all of the different feeders and then connect the transformer secondaries in parallel through the meter coils. In this case it is necessary to have a meter of sufficient current capacity to carry the sum of the currents in the transformer secondaries. It is of course necessary that all the transformers be of the same ratio and that the transformers which are connected in parallel should be in the same phase of the feeder circuit. It is necessary to asume that the voltage is the same in all the feeders in which case the potential coils of the meter can be connected to any feeder.

C.R.R.

1654—Short-Circuit Test—A test was run on one of our 13 500 k.v.a., 60 cycle, 6600 volt generators. The first test was made with all three phases short-circuited. These generators are *Y* connected and voltage during this test was measured beween the neutral and the short-circuit. The voltmeter showed approximately 300 volts. The short-circuit test was then made with a single-phase short-circuit and the voltage was again measured both from the neutral to the short-circuit and also to the open circuited terminal. The voltage from the neutral to the short-circuited terminal was approximately 1200. The voltage from the neutral to the open-circuited terminal was about 1800 volts. The question now arises, why was there any voltage on the three-phase short-circuit test since it would appear that the voltage generated would all be consumed in forcing current through the winding itself and would, therefore, not show in the voltmeter. I might further say that the reactance voltage was approximately 600 volts. Why should there be so much difference between the single-phase and three-phase voltages?

S.A.F. (ALA.)

(1) In an alternating-current generator, the resultant of the main field and the armature field is a field form which may generate a large third harmonic voltage, depending upon the relative strength of the armature and the field. This third harmonic voltage exists in each phase, and can be measured from neutral to terminal but across the terminals the third harmonic voltages oppose each other and cancel out. Thus, when the terminals are short-circuited, the third harmonic voltages do not circulate current and these voltages still appear between neutral and terminal. (2) On a single-phase short-circuit, in addition to the third harmonic generated by the resultant field, there is another third harmonic voltage set up by the double frequency current in the rotor, the result of the single-phase pulsating load.

TABLE I.

Rated Voltage	Neutral to Short circuited Terminal	Neutral to Open Terminal
13200	920	1800
13200	550	1125

This explains the higher voltage obtained on sigle-phase than on polyphase short-circuit. (3) This voltage from neutral to terminal on short-circuit exists in many generators. Results on two machines tested on single-phase short-circuit with full-load current are given in Table I. These figures would indicate that on the machine in question the voltage from neutral to the short-circuited terminal was high as compared with the voltage from neutral to the open-circuited terminal. Otherwise, the results are as should be expected.

R.A.M. AND S.L.H.

1655—Meter Connection—With two transformers connected open delta as shown in Fig. (a), will the power consumed by the motor be equal to $\sqrt{3}$ times the reading on the single wattmeter?

E.M.B. (WASH.)

The power consumed by the motor will equal $\sqrt{3}$ times the reading on the wattmeter shown in Fig. (a) only if the

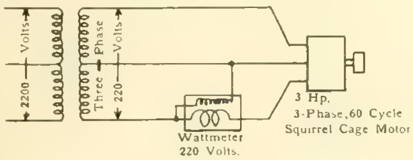


FIG. 1655(a)

load is balanced and the power-factor is unity. It is impracticable to measure three-phase power with only one single-phase wattmeter.

C.R.R.

1656—Synchronous Motor—We have tried to operate a 75 kw, 60 cycle, 220 volt alternator as a synchronous motor, starting it as an induction motor with the direct-current fields short-circuited. It stuck at half speed and we have been unable to get it by that point. It has six field poles and approximately 40 slots in the stator. If the field should be provided with copper grids for assistance in starting, would there be any guarantee that the motor would come up to 1200 r.p.m.? Can you suggest any other way than belting a small induction motor to the larger motor and using it for starting

S.A.F. (ALA.)

The fact that the machine comes up to one-half speed, and no further, indicates that the action may be similar to an induction motor with a three-phase primary winding and a single-phase secondary winding, which will, under this condition, actually run at one-half normal speed. The short-circuited direct-current field windings form a single-phase secondary winding. At the instant voltage is applied to the armature of the machine, when it is started as an induction motor, a pulsating voltage and hence current is induced in the short-circuited field windings which is of normal line frequency. This pulsating current sets up a pulsating magnetic field corresponding in frequency to the slip, or difference in the actual and synchronous speed of the machine. Therefore, as the machine speeds up, the frequency of this pulsating field gradually decreases from line frequency at stand-still to zero frequency at synchronous speed. Then at one-half speed, there will be a pulsating field of one-half frequency set up by the short-circuited field windings. This pulsating field alone will generate a counter e.m.f. of one-half normal frequency in the armature winding. Since the field poles are also rotating mechanically at one-half normal speed, with respect to the armature an additional voltage of one-half normal frequency will be generated in the armature windings. Hence, the result is a counter e.m.f. of normal frequency generated in the armature winding. This may, perhaps be more readily apprehended by considering (according to a well-known theory) the single-phase pulsating field to be resolved into two fields of the same frequency and one-half the magnitude of the pulsating field, and to be rotating in opposite directions. Then the revolving field, rotating in the opposite direction to the mechanically rotating field magnet, will have a frequency of one-half normal minus one-half normal equals zero with respect to the armature, while the revolving field rotating in the same direction as the mechanically rotating field magnet will have a frequency of one-half normal plus one-half normal equals normal with respect to the armature. Hence one field ceases to exist while the other field rotates at normal frequency with respect to the armature winding and generates a counter e.m.f. of normal frequency in it. Therefore, the machine will run at one-half speed as a synchronous motor, unless the torque as an induction motor, with the pole face as the secondary winding is sufficient to pull it by this point. It seems then that it may be possible to bring the machine up to synchronous speed by having the field windings open-circuited, so as to eliminate the action of the single-phase secondary winding. However, there is danger of excessive voltage being generated in the field windings which may damage the insulation. It may be possible to bring the machine up to speed by short-circuiting the field through a very high resistance, which would be preferable in view of the high voltage which may be generated, to having the field entirely open-circuited. Or it may even be possible to start the machine with the field windings short-circuited, so as to prevent a dangerous voltage with an arrangement to open the field circuit (through a discharge resistance) when the machine reaches approximately one-half speed. If, after starting the machine as just outlined, it still fails to come up to speed, it would seem that the trouble is simply due to insufficient torque. The alternator without a damper winding in its pole face, is comparable to an induction motor with a high resistance secondary wind-

ing, and hence may have its maximum starting torque at a low, or possibly negative speed. Therefore, when the machine is started as an induction motor, its torque falls off as the speed increases, and to such an extent that it is not sufficient to bring the machine up to synchronous speed. If this is the case, the trouble could probably be remedied by the construction of a suitable damper winding in the pole faces of the machine. This winding should consist of copper, or brass bars in the pole faces bolted to copper end rings, which are themselves bolted together between poles. A winding of this construction should be of low enough resistance to give sufficient torque to pull the machine by the one-half speed point, and up to synchronism and also still be of high enough resistance to give sufficient torque to start it, provided it does not have to deliver any excessive starting or pull-in torque, due to load conditions. M.W.S.

1657—INDUCTION MOTOR WINDINGS—What are the comparative advantages of star and delta connections for the primary windings of three-phase induction motors? When are wave windings used for induction motor primaries? A series delta connected induction motor has an open circuit in the winding of one phase. Will the motor operate open delta and how will its performance be affected? G.F. (ILL.)

The advantages claimed for delta connection are for the most part not practical and as a result the greater percentage of motors are star connected. It is claimed for a delta connection that the motor can be operated with one phase burned out and that squirrel-cage motors can be connected in star for starting and delta for running, thus getting away from the use of autotransformers. The disadvantage of the delta connection is that it required 1.73 times as many conductors in the coils as does the star for a given voltage and this results in a more expensive coil and one less rugged mechanically. The use of the star-delta connection for starting is limited for the reason that the starting torque developed is only $\left(\frac{1}{\sqrt{3}}\right) = \frac{1}{3}$ of the value when full voltage is applied and this restriction confines its use to applications where the starting conditions are fairly easy. Wave windings are seldom employed in primaries for the reason that they are not readily paralleled and in general are confined to conditions involving two or four active conductors per slot. Also they are not readily chorded and whether full pitch or chorded their overall dimension in an axial direction is greater than that of a chorded polar grouped winding. They are used where the number of poles is large and where the number of active conductors required may be reduced to exactly two or four per slot. Wave windings are preferred on rotors because of the greater simplicity of the group, or cross connections and because a full pitch winding is desired on a rotor rather than a chorded winding. The reason for the latter statement is that the output of a motor is measured by the carrying capacity in amperes of its rotor winding and the voltage generated or induced between the collector rings. Since the copper cross-section is fixed it is obviously desirable to have the maximum possible voltage generated and this is accomplished by a full pitch winding of which the wave winding is the best practical type. Also it is not necessary to have the rotor voltage any certain fixed value since it is not connected to a commercial circuit but is applied only to the starting or regulating resistance. A delta wound motor will operate with one phase dead at about two-third output. The performance will be slightly decreased at this load for the reason that the induced voltages do not quite balance with one phase missing and the corrective currents which flow in the secondary windings to balance this discrepancy cause a small loss in efficiency, power-factor and torque. This brings out another reason against the delta winding in general. If there are any electrical or magnetic or mechanical dissymmetries in the windings or in the air-gap there is a tendency for corrective currents to flow in the delta to correct the effect of such dissymetry and these circulating currents cause lower performance and heating. This point is not of great importance, but should be considered in comparing star and delta connections. A.M.D.

CORRECTION

The next to last sentence in the subtitle to Fig. 41, p. 361, in the JOURNAL for Sept. '18 should read "The ratio of torque to weight of moving element is high, and the accuracy of the instrument is not affected by ordinary fluctuations in the exciting circuit."

The Electric Journal

Vol. XV — November, 1918 — No. 11

How to Increase the Revenue of our Street Railways and Satisfy the Public

In the last issue of the Journal, the deplorable condition of our street railway companies was ably discussed by several competent authorities. Government regulation and an unfair attitude on the part of the public are very largely blamed for the bankrupt condition of the companies. The importance of these industries to the life of the country is well set forth, and admirable pleas are made for them. Confidence is expressed in the ultimate fairness of the public, when once they learn the facts, to give the street railways a square deal, but the outstanding fact remains that they must have increased revenues or go into bankruptcy.

The trouble may be in regulation but, after all, this is only a reflection of the attitude of the public, so that, if public opinion can be changed, the regulation will be a help rather than a hindrance; but granting that the Public Service Commissions were willing to give the increases in fares (which seem to have been the desiderata of all companies) is that going to have the desired result? Apparently it will not, if we may judge from the results being secured where fares have been increased. It is now well known that on these roads the traffic has fallen off to such an extent that the increase in revenue is very slight. It would therefore seem that some other scheme must be tried, and we note with satisfaction that the zone or section plan is being seriously considered. This has many advantages that commend it, not only to the companies, but to the public.

In plain language, the day for the flat rate fare has passed. Whatever may have been its advantages when railways were only two or three miles long, it is manifestly impossible, under present conditions, where they extend for many miles in all directions from the center of the city, for the flat rate to give satisfaction to both the public and the company. Any flat rate giving sufficient revenue to meet operating expenses and pay a fair return on invested capital would be an intolerable burden on many of those patrons who *have* to ride on the street cars, and it would be practically prohibitive to short haul traffic. To that extent, it would deprive a very large proportion of the people of the service they have a right to expect from a railway occupying the city streets, and it would cut off the best paying traffic. More than that, the cost of hauling each passenger would increase, due to the greater average length of ride. Increasing the flat rate, therefore, not only fails to give the necessary revenue, but limits the usefulness of the railway to the people and, therefore, still further alienates them.

If the favor of the public is to be secured, there is one thing particularly essential—they must be convinced that they are getting their money's worth when they pay street car fare, and it is going to be a difficult, if not impossible task, to convince the average person who wants to ride from one-half mile to two miles that he is getting his money's worth when he has to pay from 6 to 8 cents. As long as such conditions exist, there will be bad feeling generated that will in no wise be counteracted by those who, by riding five or ten miles, get more than they pay for. To do its full duty by the public, a street railway should make it possible for anyone who wants to ride to do so and get his money's worth.

It is just as necessary that the public should be convinced that, to do their full duty by the railway company, they should pay for the service rendered a price which will make it a financial success. It is impossible to do this with a flat rate system, and some form of zone system is the only alternative. The Glasgow Tramways reported, in presenting a check that paid off their indebtedness early in 1917, that they had carried 362 000 000 passengers in 1916, 66 percent of whom paid only one cent fare. This is a case where everybody is getting the fullest possible benefit and still the company has made money and paid off its indebtedness.

A one cent fare is entirely too low, of course, to be considered in this country, but it would seem that a rate of three cents cash or two tickets for a nickel for the first mile, with one cent for each additional mile, or two cents for each two miles, or fraction thereof, would go a long way toward producing the necessary revenue, as well as bringing about better relations between the public and the company, which are so essential to both. The railways may claim that it costs more than one cent per mile to carry passengers. That may be true at this time, but it must be admitted that it is based largely on hauling empty seats, a condition that would be radically changed by the zone system. There may also be objections on account of the assumed difficulty of collecting fares, but a system which has been working so successfully in other parts of the world should certainly be operative in this country. The principal thing necessary to bring about is to convince the companies that it will increase their revenues without increasing their operating expenses. If that were done, there would at once be ways provided that would do the trick.

One big advantage to the railway companies would lie in the abolition of the transfer system with all its abuses. By arranging zones so that transfer points coincide with zone limits any hardships result-

ing from lack of transfers will be avoided, particularly if the initial fare is low enough.

There are, of course, places in this country where so-called zone systems have been attempted, but these are in no sense of the type here suggested. Any successful zone system must have a low initial fare, and the zones should not exceed two miles in length. Such a zone system, thoroughly worked out and applied after a campaign of education had been carried on in the newspapers, would meet with great favor on the part of the traveling public. Its justice could not but be recognized, and it would be disliked only by those long-haul passengers who are now getting more than they pay for; people would get their money's worth and would recognize it. The effect on the street railways would be an immediate large increase in short-haul traffic that might require additional cars through the thickly populated sections of the city, but it would go a long way towards filling the vacant seats that are now hauled around, and would give a great increase in revenue. N. W. STORER

Power-Factor Correction

Induction motors, as applied commercially, are simple in their construction, reliable in their operation and in general have few undesirable features. They would be even more favorably regarded were it not for the fact that their magnetizing current must be drawn from the power supply circuits and, since this current is wattless, the result is a decrease in the power-factor at which the total load is supplied. Any increase in the wattless current of a system has the effect of adding to the burden on both the generator and the distributing line. As a result of this condition many methods have been proposed for correcting the power-factor of induction motors.

From a theoretical point of view none of these is more interesting than the oscillating phase advancer originally proposed by Dr. Gisbert Kapp and described by Mr. C. W. Kincaid in this issue of the JOURNAL, for the reason that it accomplishes the very curious result of converting mechanical inertia into electrical phase displacement. The article is worthy of careful attention for this point alone.

Because it offers an improvement in induction motor operation, this type of phase advancer is of wide interest, but a word of caution is advisable as to its limitations. The most serious of these is that it cannot be employed in connection with a squirrel cage motor but only in connection with wound rotor machines. A further consideration is that the results secured depend upon mechanical reciprocation, which means that the slip of the motor to which it is connected cannot be much greater than four percent on 25 cycles or one and two-thirds percent on 60 cycles. This condition eliminates reversing motor installations, and all cases where the speed of the main motor must vary over a wide range, as it does in hoisting work. Since this limits its use to constant speed work, some applications which are suitable for the combination of induction motor and phase advancer can also be taken care of by using a synchronous motor to drive the load, provided the starting conditions are not prohibitive. With a synchronous motor, the power-factor of a system can be corrected by a constant amount, regardless of the load on the motor itself, and for this reason a synchronous unit is preferred where use can be made of this characteristic. Again, since the phase advancer is inserted in series with the motor secondary, it must be designed to fit the secondary voltage and current of that motor and cannot be applied indiscriminately to other motors. Where a number of units are being operated and some of the units are operating at varying speeds, a synchronous condenser floating on the line and operating at relatively high speed would give a more economical and flexible means of power-factor correction.

If the motor, to which the phase advancer is applied, is originally designed for use with an advancer a saving in material may be accomplished to offset the cost of the advancer but, where the advancer is an afterthought, its cost is additional to that of the motor and should be balanced by the increase in the torque and capacity of the motor and in the benefits to the system as a whole resulting from the improved power-factor.

This is a unique application whose theory is more than ordinarily interesting and, where suitably applied with the interests of both the motor user and power supplier in view, phase advancers will undoubtedly demonstrate their usefulness. A. M. DUDLEY

Circuit Breaker Ratings

An oil circuit breaker differs from other electrical apparatus in that its bulk is only partly dependent on its rated voltage and current carrying capacity. Because its size is dependent also on the capacity of the generators and intervening transformers which feed the circuit, the selection of a unit having a suitable breaking capacity rating is of increasing importance in the larger plants and, in these days of interconnected stations and substations, is becoming increasingly complicated. The methods for determining the proper breaking capacity rating, as well as the fundamental principles upon which a successful circuit breaker structure must be based, are discussed fully by Mr. J. N. Mahoney in this issue of the JOURNAL. A circuit breaker which meets the requirements outlined in this article will be successful, not necessarily regardless of detail, but because correct details are thereby ensured. Hence in selecting a circuit breaker one needs to know only: What is the maximum current possible at the point of application; will the circuit breaker open this maximum current; how quickly will it do it; will it then be able to do it again? CHAS. R. RIKER

45 000 Kw Cross-Compound Steam Turbine

Of The Duquesne Light Company, Pittsburgh

J. P. Rigsby

There has recently been put in service in the Brunots Island power station of The Duquesne Light Company at Pittsburgh, a 45 000 kw cross-compound turbine-generator unit, whose service is most opportune, coming at a moment when electrical energy is so urgently needed in the Pittsburgh district in all lines of war endeavor.

The cross-compound idea is not new, of course, even in steam turbine practice, a most successful example being the three 30 000 kw units which have been in operation for some years in the 74th street power station of the Interborough Rapid Transit Company, New York, while in the same power station has just been installed the largest turbine yet constructed, a three-cylinder, cross-compound unit of 70 000 kw capacity.

This new 45 000 kw Pittsburgh unit consists of separate high and low-pressure elements, each coupled directly to its own generator. The high-pressure element is a single-flow, reaction-type turbine, running at 1800 r.p.m. and expanding to atmosphere. The low-pressure element is a double-flow turbine of the same type, running at 1200 r.p.m. and expanding to vacuum.

The reason fo. dividing a large capacity turbine into two or three elements running at different speeds is obvious. A certain quantity of steam has to be passed, which may increase in volume one hundred and fifty times, between inlet and exhaust, and drop five hundred degrees in temperature. This means beginning with very short blades on a small drum and ending with very long blades on a large drum. If these are all put on one spindle it is inevitable that considerable compromise must be made at the extreme ends, with a resultant loss in efficiency; and furthermore, the wide range of temperature in the same cylinder may cause troublesome distortions. With the use of two or more cylinders, the expansion is divided, making it unnecessary to resort to a compromise in blading distribution or velocities. The high temperature can be confined to one cylinder of smaller size and simpler construction, and not endanger the necessarily large size low-pressure sections. This may result in a more expensive construction, but is warranted by a greater efficiency and dependability.

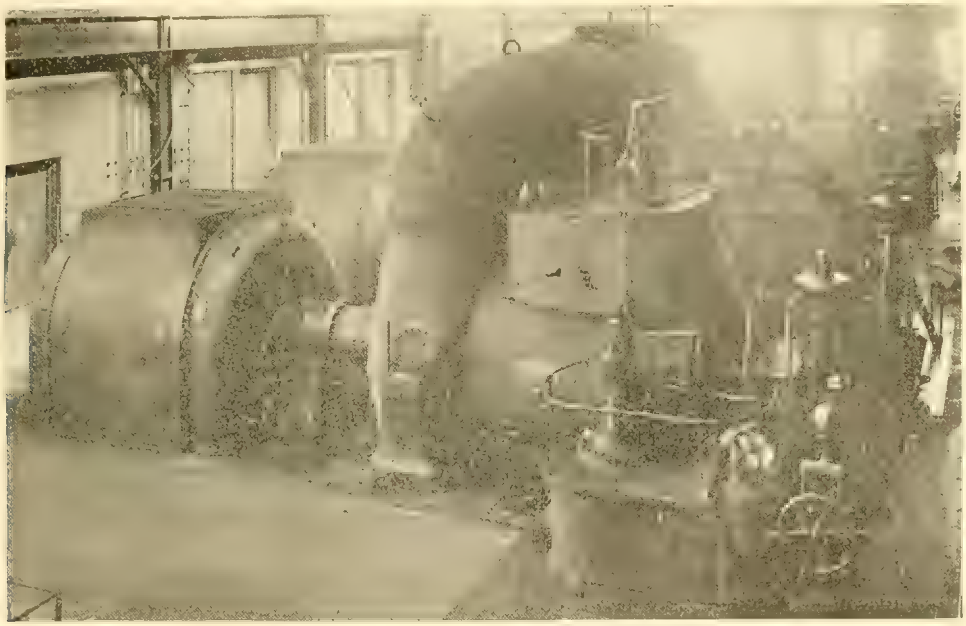


FIG. 1—45 000 KILOWATT CROSS-COMPOUND STEAM TURBINE
Showing the high-pressure turbine and generator with throttle valve and steam chest in the foreground, and the low-pressure turbine and generator beyond.

Steam is supplied through a 24 inch main to the high-pressure turbine. It passes first through an automatic throttle valve, a steam strainer, and a governor controlled primary valve, and then enters the high-pressure cylinder from below. The steam chest, strainer etc. are spring supported and are carefully aligned to remove the possibility of outside forces being exerted on the turbine cylinder, sufficient to cause distortions when the parts are expanding and contracting under load. Steam is exhausted from the opposite end of the high-pressure cylinder at about atmospheric pressure, when running at full load. The exhaust steam from the high-pressure cylinder passes into a cast iron overhead receiver pipe, which leads to the center of the low-pressure turbine where it divides, flowing either way into surface condensers below.

In connection with the marked increase in the ca-

pacity of steam turbines of late years, it is interesting to note that the size of the turbine has not increased in proportion to its capacity, owing to the development of the high-speed alternating-current generator; whereas the steam pipes have proportionately increased. This presents the problem of so arranging the header, that it will have a maximum flexibility at the point of contact with the turbine, and will not disturb the alignment or distort the cylinder by its expansion or contraction.

A 66 inch gate valve is located in the receiver pipe midway between the two turbines, for the purpose of isolating the one from the other in case of a shut down. Provision is made for the valve to be closed automatically in case either element should get into difficulty, and the necessity arise for its immediate removal from the line, without disturbing the other. This is accomplished by a specially equipped governor on the low-pressure turbine, which will be described later.

The turbine is designed to operate with 200 lbs. gauge steam pressure, 200 degrees superheat at the throttle, and an absolute pressure in the exhaust of one inch of mercury. The pressure in the receiver pipe is 12 lbs. absolute at 30 000 kw. The generators are each 23 600 k.v.a., three-phase, 60 cycles, excitation being provided separately. A double condenser is provided containing 28 000 sq. ft. cooling surface in each shell and capable of maintaining a 29 inch vacuum with a load of 35 000 kw, and 60 degrees cooling water.

This big unit is not radically different from the others of the same type. A distinctly new feature is the automatic device for cutting out either turbine if, for any reason, its immediate removal from service becomes necessary. By this means all the economic advantages of a 45 000 kw machine are obtained with the flexibility of a 22 500; that is, it is necessary to carry in reserve only 22 500 kw rather than 45 000, as would be the case if it were a single cylinder or tandem machine. Each turbine and generator rotor is supported in its own bearings, so that four bearings are required for each element. They are heavy cast iron shells lined with babbitt and split horizontally, the upper half fitting into the lower, to prevent any side movement between the two halves. The bearings are self-aligned, being supported on spherical keys with sheet metal liners of definite thickness underneath, for horizontal or vertical adjustment. Oil for lubrication is admitted to the bearing casing at the bottom, is conducted through internal pipes to the top and distributed over the length of the journal through an oil groove. The sides of the bearing are eccentrically relieved for a space of about 35 degrees above and below the center line, to within an inch of each end, thus providing a reservoir of oil along each side. The journal is thus supported on an arc of about 110 degrees. It has a peripheral speed of 75 feet per second and a pressure of 110 lbs. per sq. in. on the projected area of the bearing.

Both turbines are equipped with Kingsbury thrust bearings capable of taking load in either direction, though when running the thrust is toward the generator. Under normal operation they are loaded to about 300 lbs. per sq. in., but are capable of safely carrying twice as much. The peripheral speed is about 100 feet per second. These bearings are not only immersed in oil, but are supplied with a circulation of fresh oil through internal passages which deliver it nearer the shaft. The couplings are of the flexible pin type* providing sufficient flexibility to take care of any ordinary misalignment due to improper setting or to deflection of shafts.

The shafts are sealed with a water-gland which operates on the principle of a centrifugal pump, maintaining a water seal with a head greater than atmosphere, thus preventing air from leaking through the water filled chamber and into the exhaust. A steam seal is provided in an additional chamber along side the one in which the paddle wheel revolves, into which steam is admitted at a pressure of about five pounds gauge, or a

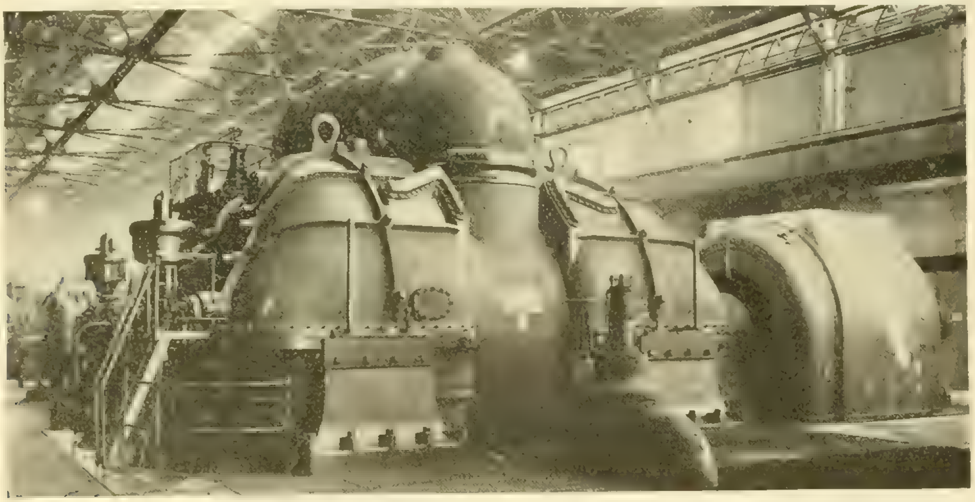


FIG. 2—45 000 KILOWATT CROSS-COMPOUND STEAM TURBINE
Showing the low-pressure turbine and generator with auxiliary exhaust steam connection in the foreground. The overhead receiver pipe can be seen on top.

*See article on "The New Commonwealth Turbine" by Mr. J. F. Johnson in the JOURNAL for June 1918, p. 194.

little above atmospheric pressure when starting up. This prevents air from leaking through the gland into the turbine while it is being brought up to speed or until the gland becomes operative. When running the steam is turned off.

The high-pressure turbine is of the single-flow reaction type. The entire cylinder or casing except the exhaust end is made of cast steel. The internal blade rings are separate and bolted in place.

High-pressure steam is admitted to the cylinder from below through the primary inlet, as shown in Fig. 3. It passes through the successive rows of blades and out through an overload exhaust to the low-pressure turbine. This particular turbine is arranged to carry 30 000 kw on the primary valve with 175 lbs. steam and 100 degrees superheat at the throttle and 28.5 inches vacuum in the exhaust. For a load between 30 000 and 40 000 kw steam is admitted through the secondary valve, thus by-passing the first five rows of four inch blades and entering the second stage which has five inch blades. This gives greater capacity but at a reduced efficiency. Similarly for loads above 40 000 kw steam is admitted directly to the third stage, starting with six inch blades. The limit of capacity is approximately 50 000 kilowatts.

There are 24 moving and the same number of stationary rows of blades in the high-pressure turbine, beginning with four inch blades one inch wide on a 36 inch drum and ending with 10.5 inch blades 1.25 inch wide on a 50 inch drum.

The rotor is composed of three main parts, the body and two ends, besides which there are two blade rings on one end and two dummy rings on the other. The ends are pressed into the body on long taper fits and secured by tee-headed shrink links, making a thoroughly secure and rigid construction with a calculated deflection at the center of not over seven thousandths inch and a critical speed of 2300 r.p.m. The normal speed being 1800, there is left an ample margin to insure smooth running when properly balanced.

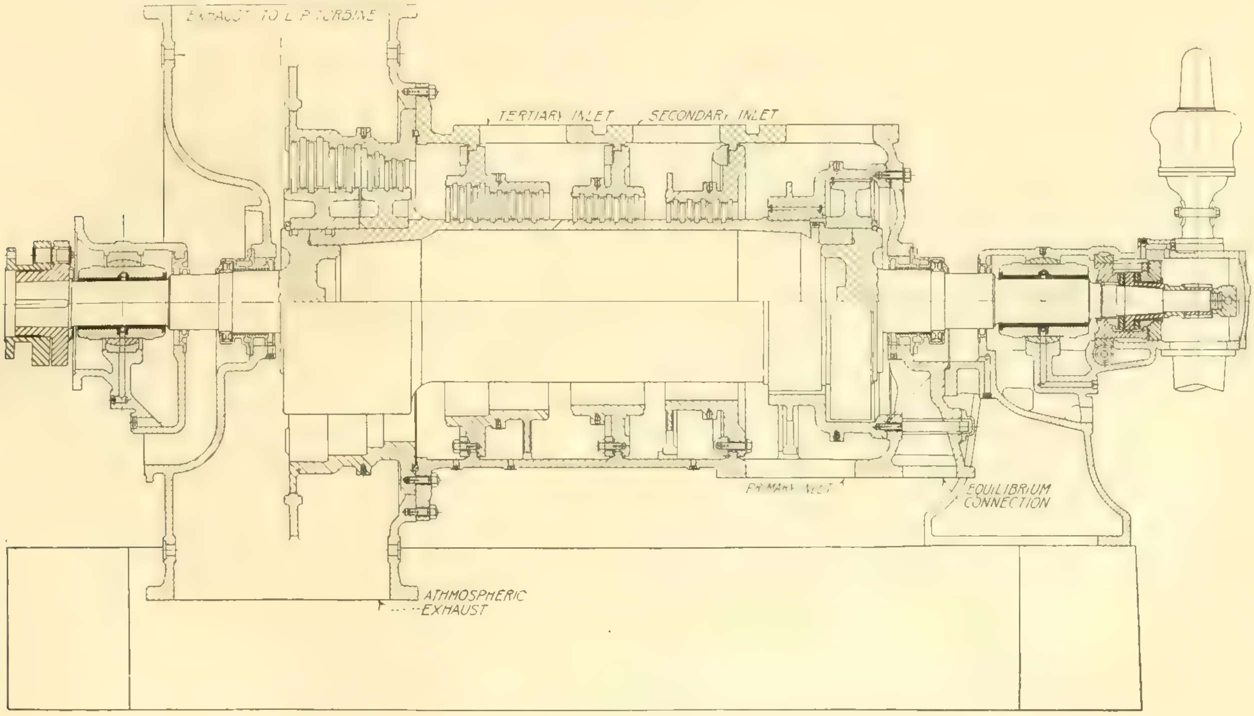


FIG. 3—SECTION THROUGH THE HIGH-PRESSURE SINGLE-FLOW TURBINE

The low-pressure turbine is of the double-flow type as shown in Fig. 4. Steam enters the center section and flows both ways, passing through eight rotating and eight stationary rows in each end, varying in length from six to eight inches, then passes into the exhaust chamber and down into the condensers below. As the load is divided equally between the high-pressure and low-pressure turbines at full load, the steam enters the low-pressure turbine at about atmospheric pressure.

The cylinder or stationary part is of cast iron and is composed of center and end sections, the blade rings being cast integral with the cylinder. The three sections are bolted and spigoted together and all are split horizontally. The upper three pieces are handled as one, the vertical joints never being disturbed after they have been once assembled.

The turbine rests on four supports applied directly below the horizontal joints, on each side of the exhaust chamber, and in line with the center of the exhaust opening. It is free to expand axially, sliding on these supports, with the turbine anchored to the inboard generator pedestal. A system of radial and axial stays in the exhaust chamber gives ample support for the spindle bearings and produces extreme rigidity in the whole structure, minimizing the possibility of distortions with change of load, or due to external pressure.

The low pressure rotor is composed of a central hollow drum rigidly secured to spindle ends on each of which is pressed two blade rings or discs carrying the low-pressure blades. The maximum mean velocity of

the blades is only 515 feet per second which precludes the necessity of using other than a good grade of cast steel in the blade rings, as the rotative stresses do not exceed 20 000 lbs. per square inch at 20 percent overspeed. This has a distinct advantage over a design containing special grade steels, which are not only hard to get, even in normal times, but in the use of which a certain hazard is always taken, through the possibility of an undetected flaw, or some part not being up to specification, and besides a little abuse in the way of improper heat treating on a highly stressed part may result in a costly failure. Owing to the double flow feature, ample blade area is provided to take full advantage of a high vacuum and still maintain a reasonable blade length in the last rows. Phosphor bronze blades are used, except in the last three rows of the spindle, which are drop forged steel.

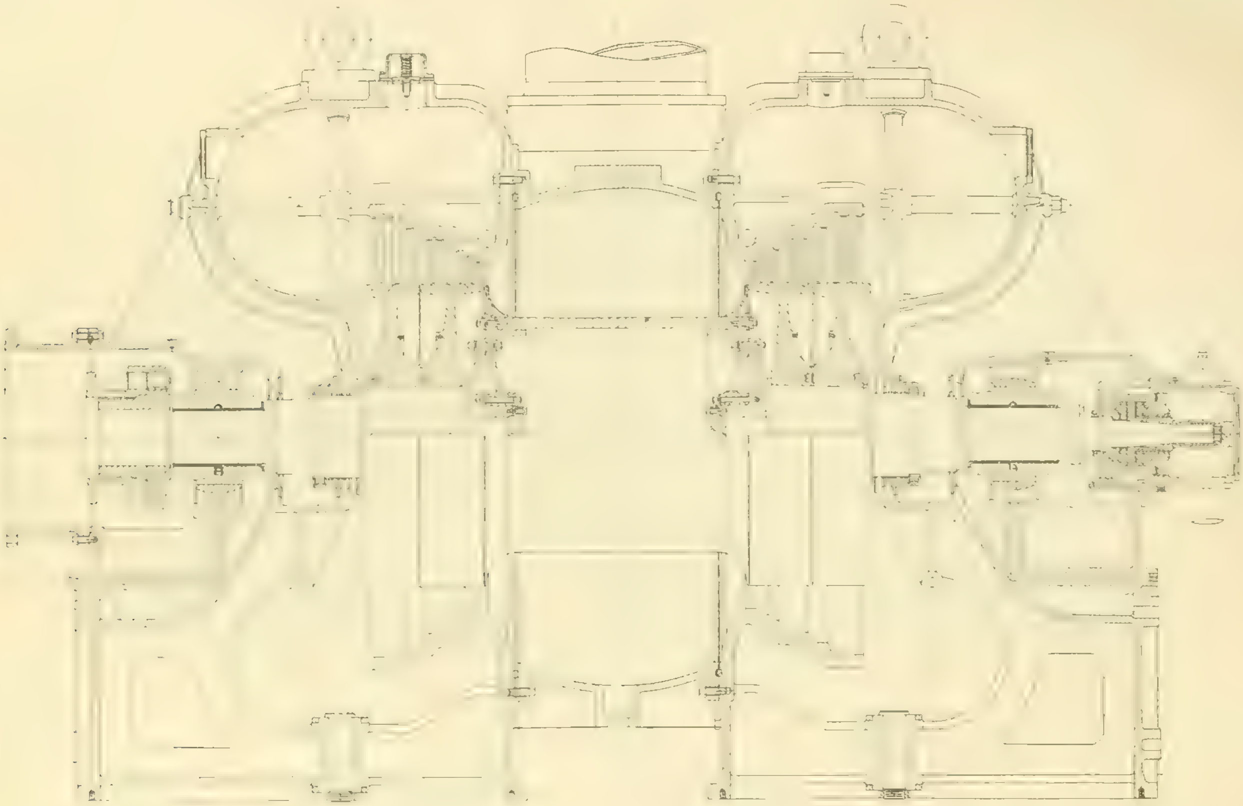


FIG. 4—SECTION THROUGH THE LOW-PRESSURE DOUBLE-FLOW TURBINE

One of the principal features of interest on this turbine is the means whereby, in case of necessity, either machine may be automatically or manually cut out of service without disturbing the other. Each turbine is provided with an over-speed stop governor which will shut off steam to that unit in case the speed should rise ten percent above normal. Each unit also has a speed control governor. The one on the high pressure turbine, which normally controls the steam supply to the whole system, is of the customary form. The governor on the low pressure element, while essentially the same, has some special features.

A gate valve is placed in the 66 inch receiver pipe, connecting the high and low-pressure cylinders, which is automatically closed by a hydraulic piston, under the control of the low-pressure governor, in case the low-pressure turbine should overspeed. The high-pressure turbine is provided with an emergency exhaust which will, in such an event, open to atmosphere through a relief valve, the turbine still continuing to carry load. Similarly if the two turbines are running together and the high-pressure element should lose its load, steam will be shut off by its governor, when it will continue to run with no load, or if it should overspeed, the steam will be entirely shut off by the overspeed governor. In either case, through lack of steam, the low-pressure turbine will slow down a certain percentage below normal speed, when the governor on the low-pressure element will open the governor valve and admit live steam directly.

The governor on the high-pressure turbine is adjusted for the usual close regulation of about three percent over the full range from no load to full load. The governor on the low-pressure turbine during this time must, of course, be inactive, neither admitting high-pressure steam through the steam chest, nor closing the valve of the receiver pipe. In this way, the travel of the low-pressure governor is divided into three zones:—the outer position, in which the gate valve admitting steam from the high is operated; the inner in which is controlled the admission of high-pressure steam, when other source has failed; and the middle position, or neutral, where the high-pressure governor is controlling the system, and the low-pressure governor has no effect on the admission of steam, but is simply running idle.

It is desirable of course that the low-pressure governor should not be called upon to perform any of

its functions, except in the case of an emergency, and in order that this position may be maintained properly by the switchboard operator, a system of signal lamps is arranged to show its position in the neutral zone. By changing the tension of the speed changer spring, the governor may be kept in its middle position, so that a normal fluctuation of frequency will not cause the governor to function. The spring on the low-pressure governor is designed to give a total speed range of twelve percent which is divided up as follows: Starting from the central position, if the speed rises four percent the governor is on the verge of tripping the low-pressure inlet valve. With a further rise of less than one percent the valve will be tripped shut, one more percent travel being provided for clearance. From the central position downward, should the speed decrease two percent the high pressure valve will begin to open and will be full open after three percent more decrease. Another one percent is also provided at this end for over-travel.

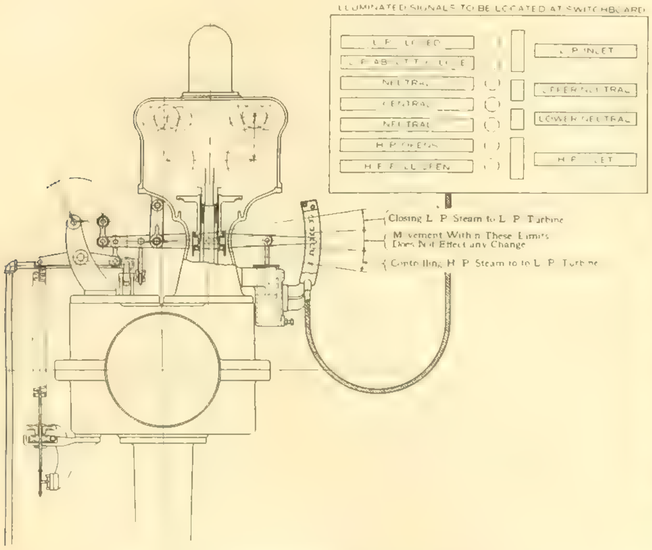


FIG. 5—LOW-PRESSURE TURBINE GOVERNOR

Showing diagramatically the method of indicating the position of the governor.

The signal lamps in the switch board gallery, Fig. 5, are controlled from the low-pressure governor by a system of contacts operated by an extension on the governor lever. As the governor moves between its inner and outer position this lever travels across the contacts, registering its position on the illuminated sign.

To review the system briefly:—If the circuit breaker on the low-pressure element should open due to a short-circuit, the turbine will speed up and close the steam inlet from the high-pressure cylinders. The high pressure turbine will continue to run, carrying its load and exhausting to atmosphere, while the low-pressure turbine, with its source of steam cut off, will fall in speed until reaching two percent below normal, when the governor valve will admit high-pressure steam. In the meantime, if the line has been cleared the unit may be synchronized and reconnected to the bus bars, the gate valve opened, and the low-pressure cylinder receive its steam as before. If the low-pressure turbine for similar reasons should overspeed ten percent and the automatic stop operate, it will result in the automatic closing of the high and low-pressure steam inlets, and the opening of the circuit breaker, and thus this half of the turbine will be entirely shut down. The high pressure element, however, will continue to run non-condensing and carrying its load as usual.

If the circuit breaker on the high-pressure turbine should open and the load be dropped, the supply of steam to the system would diminish, and the speed would fall until the low-pressure governor valve opened, admitting high-pressure steam to carry load. The connection from the high to the low-pressure cylinder would remain open, the no-load steam on the high-pressure element continuing to help run the low. After the electric difficulties have been removed the high-pressure generator can be synchronized and placed back on the line and the load carried as before.

If the high-pressure turbine should overspeed ten percent through some local cause, and the automatic

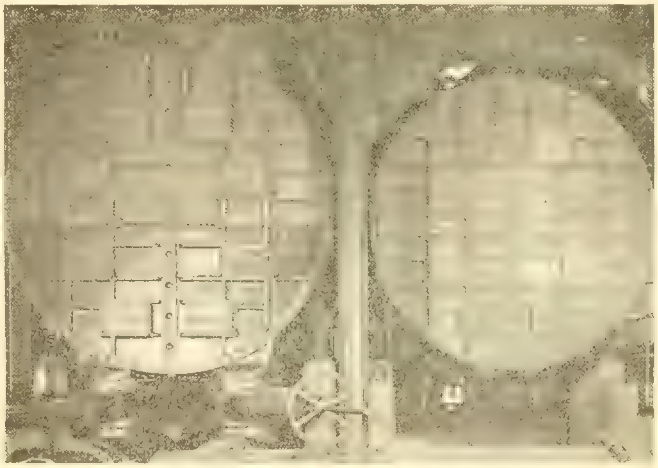


FIG. 6—TWO 28 000 SQ. FT. SURFACE CONDENSERS

Showing the divided water box with double connections, and the method of spring supporting.

stop operate, the main throttle and governor valve would close, shutting off all steam to the system. The circuit breaker would open and the machine shut down. The speed of the low-pressure element would immediately drop until its governor valve opened to admit high-pressure steam to carry the load. In this case the steam seal on the high-pressure glands should at once be turned on to prevent an air leak into the system unless, however, the inlet pressure is kept above atmosphere. In case it is necessary to run the low-pressure turbine alone for any length of time, the gate valve in the receiver pipe should be closed.

Attached to each throttle valve and operated by it is a switch whose function is to operate the main circuit breaker. The throttle valve is tripped out by the emergency stop and in this way not only is the turbine absolutely isolated, but the generator also. The operation of the throttle valve by hand, however, does not operate this switch.

The low-pressure element, is served by two 28 000

sq. ft. surface condensers or a total area of 56 000 sq. ft., which are shown in Fig. 6. The condensers are spring supported, there being no expansion joints between the low-pressure turbine and condensers. They depart from the standard construction in that the circulating system of each condenser is divided into two parts, so that one half can be in operation, while the tubes in the other are being cleaned. Each condenser is equipped with two water inlets and outlets, and also has two air off-takes, one on each side of the condenser shell. The condenser is supplied with 74 000 gallons of cooling water per minute, by three circulating pumps of the double impeller type. All the circulating pumps are turbine-gear driven. The air removel apparatus consists of two sets of Westinghouse-LeBlanc wet air pumps, shown in Fig. 7, each of which is capable of completely removing the air, so long as the leakage is normal.

The water supply for the air pumps is taken from a steel tank. Both sets of pumps discharge into one tank, and the air pump water is used over and over again.

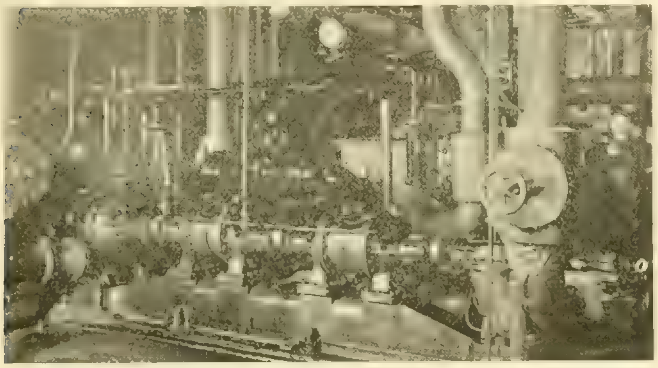


FIG. 7—TURBINE DRIVEN AIR AND CONDENSATE PUMPS

Of course this arrangement requires a certain amount of make-up water to keep the temperature of the air pump water down to normal. This is taken from the service line. The overflow from the air pump tank is ordinarily discharged into a sump. Due to the fluctuating water conditions at Brunots Island Station, booster pumps were also supplied in order to take care of the overflow during periods of high water in the river. The condensate is removed by means of centrifugal pumps, each of which is capable of handling the maximum condensate. The air and condensate pumps are driven by the same turbine, but are not on the same shaft, there being a coupling between the air and condensate pumps.

The circulating, air and condensate piping is connected to give a very flexible arrangement. Since the auxiliary pumps are in duplicate, it is possible to remove any one of them for inspection or repair.

The two three-phase, 60 cycle, 12 000 volt generators are designed for the same output at full load. The one connected to the high-pressure turbine has four poles and runs at 1800 r.p.m., while the one connected to the low-pressure turbine has six poles and runs at 1200 r.p.m. In spite of this considerable difference in speed the D^2L as measured at the outside diameter of the punchings, as well as the length of the core, is almost the same in both cases, it being but 3.5 percent higher in the low-speed generator. On the other hand, the D^2L measured on the active diameter and length of the rotor is 45 percent higher in the low-speed machine. The reason for the D^2L being nearly the same at the outside diameter is due to the fact that the high-speed machine has a considerably greater depth of punching back of the slots, because of the larger flux per pole per inch of length axially.

Each generator requires approximately 70 000 cu. ft. of air per minute for cooling. With this large volume of air, the air temperature rise, and the iron temperature rise are both comparatively low. The air is supplied from separate blowers, and the two machines require approximately the same pressure to circulate the needed air through them, this pressure being about 4.25 in. of water. All the air is washed before it enters the generators, thus insuring against clogging of air ducts and tending to decrease danger of burnout. Air to the amount of one and one-third times the weight of the generators passes through them per hour. Also approximately 1.4 times the weight of steam needed to drive the generators with full load of 40 000 kw, is required in air for cooling.

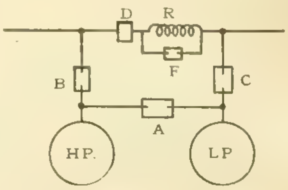


FIG. 8—DIAGRAM OF GENERATOR CONNECTIONS

The stator insulation in the buried portion in both machines is mostly mica, and is capable of withstanding continuous temperatures of 150 degrees C. The rotor insulation in both machines also is mostly of mica, and is capable of withstanding the same temperatures as the stator. The stator coils of both machines have but one turn each, there being parts of two coils in each slot. That only one turn per coil is needed with 12 000 volts is due to the fact that the generators are so large, and a small number of turns in series is required to generate the total voltage. With one turn per coil, there is no danger of break-down between turns, which is an important item with over 200 volts per turn, and a breakdown between turns would mean not only the destruction of the insulation, but would also probably be accompanied by great damage to the core. In order to reduce the eddy curent loss in the stator coils to a point where the temperature will not become dangerous, the coil is well stranded, and the strands are transposed from one coil to the next, thus bringing the top set of strands of the first coil in series with the second set of strands of the second coil, the third set of strands of the third coil, etc.

In order to protect the generators in case of fire, arrangements have been made to inject steam into the air intake just below the entrance to the end bells and, in addition, there is provision for shutting off the air as soon as fire is discovered. This means has been found to be quite effective.

The generator fields were designed to have approximately the same exciting voltage at full load as that required by the other generators previously installed in this station, and with which this unit is to operate in parallel. This enables fairly efficient operation, as very little external resistance is needed in series with the field windings of the generators when an automatic regulator is used. It also permits the use of a common storage battery for emergency excitation of this and the other units.

The scheme whereby the two generators are paralleled is given in Fig. 8, in which *A* is a switch which is manually operated and is used only to connect the two generator windings together when the unit is started. When starting, with this switch closed, the fields of the two generators are excited so that the two units are kept in step from a standstill. When the machines are up to speed, the switch *A* is opened. *D* is a nonautomatic circuit breaker, *R* is a reactance, and *F* is a circuit breaker which opens in case there is a short-circuit on either side of the line. In case of a short-circuit the reactance *R* prevents a prohibitively high current from flowing from the second machine to the point of breakdown. *B* and *C* are differential automatic protective devices for the two generators.

Saving Coal for Victory

G. N. Allen
Acting Director, Conservation Bureau,
United States Fuel Administration

INDUSTRIAL production is almost entirely dependent on coal. So rapidly is our war machine growing that it will require 100 000 000 more tons of coal this year than were mined last year. Even in times of peace such a coal production has never been reached; how can we look for it now when mine labor has been inducted into the army and when railroads are burdened beyond their capacity to transport troops and army provisions? Is it not astounding that, in the face of these difficulties, the United States Fuel Administration speeded up production to the extent that last year 50 000 000 more tons were mined than in the year previous to the war and that this year this total will be increased by 50 000 000 additional tons. Still we shall lack 50 000 000 tons of the required 100 000 000. Yet because the war depends on steel and steel depends on coal we must have more coal than can be mined.

Conservation of 35 000 000 tons in industrial and 15 000 000 tons in household consumption has been the means of diverting to the steel mills a sufficient fuel supply essential to winning the war.

In some instances, power plants have wasted fifteen percent of their fuel energy, most of which waste can be redeemed without replacement of machinery, merely through efficient operation and correct supervision. The United States Fuel Administration, through competent and efficient departmental organization, is co-operating with industry, in order that the best interests of economy may obtain.

A field for great economy exists in the conservation of coal used for the generation of electrical energy. The methods suggested involve little inconvenience and frequently result in reducing the cost of operation of the individual power plant while saving coal to be diverted to war industries. Managers of buildings operating isolated power plants, frequently can obtain economies by substituting central station service. In the large central station the unit cost of production per kilowatt-hour is very low, and the generation of electrical energy can be accomplished with a far greater economy than in smaller and less efficient plants. The cost of the service connection is usually borne by the central station, and the electric generators and auxiliary apparatus may be utilized by the private plant on the return to normal conditions.

It is estimated that in round numbers there are between 25 000 and 30 000 private electric generating plants. Among a few important centers nearly two hundred private plants are purchasing electrical energy, resulting in a probable saving of more than 150 000 tons of coal a year. It is hoped that these cases will give impetus to a national movement favoring central station service wherever possible and economical.

The interconnection of power systems which parallel each other is another measure which will result in large fuel economies, because when the load is sufficiently light only one of the power houses need operate; in such a case it would be the more efficient plant. A power plant depending on coal can be connected with one of hydroelectric development so that, except in times of peak load, the power may be supplied by the hydroelectric system. The majority of hydroelectric developments are not able to take on extra loads. Yet there are some stations which could generate more kilowatt-hours by securing secondary customers. In order to do so, it would be necessary to rearrange their present contracts or secure certain new rights. Some hydroelectric power plants have no storage capacity and there is a resultant water waste over the dam at night, on holidays and at light load. If a secondary load were transferred from a steam power plant at these times the fuel economy would be considerable. As an illustration, the Mississippi River Power Company, a hydroelectric development, sold "when available" electrical energy to the Union Electric Light & Power Company of St. Louis, and by this means effected an economy at certain seasons of the year, as shown by the conservation of 20 000 tons of coal a month.

A desirable conservation measure is the more universal construction of storage reservoirs which will take care of excess water and lay up the supplies of the spring floods to be used in seasons of drouth and of heavy loads. The power plant of the Western Vermont Power Company has availed itself of the storage facilities of Bomoseen Lake. The power conserved by this storage reservoir is the equivalent of what would be produced by approximately 2500 tons of coal in a year.

Many power plants are operating with defective machinery. Every leaky valve means wasted power and all inefficient apparatus should be replaced. When complete replacements of equipment become essential to greater efficiency in production, the high costs of labor and material, and delayed deliveries of apparatus by the manufacturer are usually effective arguments against new installations at this time, particularly when an absolute shut down is involved. Coal priorities permit partial operation of power plant during the period of replacement and reconstruction.

Where a stream has not been too highly developed already, the addition is often possible of one or more units which will supply secondary power at certain times of the year. These add nothing to the minimum power of the plant, but only to its secondary capacity and may be open to economic objections except where the original construction anticipated the changes and built with them in view. Investigations of plants are under way to determine in which it is wise to make such changes; river-flow data, load curves, steam stations and other determining factors must be considered and weighed before decisions are reached.

It happens sometimes that plants are partially constructed and then abandoned owing to financial and legal difficulties. In many cases, financial assistance or the clearing up of some complexity in the law will result in the rapid completion of the project. The Blue Ridge Power Company, for instance, by securing needed supplies of coal and current was able to complete a valuable development, which will replace about 30 000 to 35 000 tons of coal a year.

The labor, material and time required for new hydroelectric developments render impracticable their construction on a large scale at the present time, although they would yield large ultimate returns. Investigations are made of promising and possible cases of water development as soon as they become known to the State Fuel Administrator. Thus where the district engineer of the United States Geological Survey is affiliated with the States conservation work, as is usually the case, he is asked to make the investigations and the report. According to his findings the important question is answered: "Will this use of labor and materials contribute more toward winning the war than some other measure in which less labor and material could be used?" If this is answered negatively, the project is abandoned. The second question is: "Will it be financially attractive?" When both questions are answered affirmatively, the Fuel Administration is ready to give assistance of whatever kind is advisable.

There is a difficulty which interferes often with these projects. Measures designed for the fuller use of water power as a substitute for coal must be undertaken by the public utilities companies. These have not shared in war prosperity and are not in a position to finance improvements and extensions. The War Finance Corporation occasionally can lend assistance but usually is obliged to confine its help to coal-construction projects. The Emergency Power Bill has been introduced in Congress to meet this situation.

Where plans for the development of additional storage or other improvements are blocked by inability to secure land or permissions, the Fuel Administrator can intervene in behalf of a friendly settlement. Legislative enactments have not made it easy for financial interests to secure rights for water developments. The Water Power Bill is intended to make possible a number of developments which are now inactive. The Fuel Administrator can sometimes recommend to the Priorities Board favorable action with regard to equipment or supplies needed for construction, or to secure needed commodities which are not the subject of priorities. The Emergency Power Bill will, if passed, make possible the undertaking of enterprises not remunerative enough to attract private capital, but which would speed up the winning of the war.

Economy is not confined to new and improved construction. Much fuel is wasted by neglect of machinery and careless methods of operation in factories. Parts which are not clean and thoroughly lubricated, slipping belts, excessive sparking, erratic speed, the running of motors when machines are idle, the faulty grouping of machines so that more motors operate than would be necessary if distances between machines were reduced —all these things waste coal which could produce the steel our armies must have in vast quantities to make their courage and skill effective against the enemy.

Coal wasted in the careless use of current used for light should be conserved. If windows were kept clean sunshine could enter the rooms at certain hours, supplying without cost the best kind of lighting. At other hours economy can be effected by the grouping of lights so that the fewest burners may supply illumination to the greatest number of people. Where this is not possible workers may sometimes be grouped favorably under the clusters. Efficient burners must replace less efficient ones, tungstens take the place of carbon filament lamps and nitrogen-filled ones the place of arc lights. Drafty doors and windows and unprotected staircases result in the consumption of fuel a large part of which is wasted because it does not heat adequately the apartments which drafts are continually chilling. Factory operatives should be urged to wear warm clothing as a coal-conservation measure. In order to set in motion all possible economies in the operation of factories the Fuel Administration recommends the appointment of a shop committee in every factory which shall keep in touch with all details in the operation of the

plant where economies could be installed and make records of savings.

America has been renowned among nations for its lavish use of ice. The unhealthfulness of ice water and other chilled drinks and frozen foods has been preached to us without much result. Now the conservation of ice is a patriotic measure because ice, like almost everything else, is made by coal power. Its wasteful use and its employment for purposes of display should cease. Several plans are under consideration as means of conserving fuel in refrigerating plants. It is suggested that coal be allotted to them on the basis of a ten or fifteen percent reduction over their consumption last year. The closing of certain plants in the winter, which in summer would operate again, is another plan. It would carry with it a proviso permitting the owners of inoperative plants to buy at wholesale from those which have not been closed, thus protecting them against loss. Power is used for agitation in raw-water plants, merely in order to manufacture the clear transparent block to which we are accustomed. If ice were marketed as a white, opaque substance, this fuel-consuming power would be eliminated.

The skip-stop is becoming a familiar method of fuel economy. The United States Fuel Administration hopes that all cities with populations of 25 000 or over will adopt it as an immediate act of patriotism. This is the skip-stop slogan:—

It will save 1 500 000 tons of coal per year.
More coal means more steel.
More steel means more guns and ammunition.
More guns and ammunition, a shorter war and fewer casualties.

The skip-stop will save coal because six or eight times as much current is used to start a car as to keep it in operation. The old system of stopping on signal resulted in as many as twelve or fourteen stops a mile; whereas the skip-stop stations are placed approximately one-eighth of a mile apart in business districts, one-sixth in residential and a quarter of a mile apart in open country. Moreover, this system eliminates stops on the sides of hills and around curves requiring excessive power. Cities where this system is in operation report that the inconvenience occasioned to passengers is compensated for by the more rapid service which the cars give. Far more important, however, than this compensation for slight personal inconvenience is the fact that were this system established the country over 1 500 000 tons of coal would be set free for distribution in war factories.

The conservation program of the United States Fuel Administration is worked out logically from reliable statistics and with the principle always before it of bringing about the greatest saving of coal with the least sacrifice of comfort. If the public co-operates intelligently and heartily with the Administration, we shall be able to supply our splendid men abroad with the arms and ammunition which will enable them to hasten the day of freedom.

The Design of Porcelain Insulators from the Theoretical Standpoint

G. I. Gilchrist and T. A. Klinefelter

It is evident from preceding papers* that the producton of a satisfactory porcelain insulator is dependent largely upon the quality of the porcelain body. The characteristics of porcelain of different proportions of ingredients were not given due consideration in the first high voltage pin type designs, due primarily, to a lack of knowledge of these properties. A study of present commercial designs indicates that the theoretical principles have been approached in certain cases, but that these principles have not been thoroughly understood nor carefully applied.**

STATEMENT OF A PRINCIPLE OF ELECTROSTATIC THEORY

If a region in any particular electric field be isolated by any number of closed surfaces and if the potentials at all points on the enclosing surfaces are maintained at their original values, then the electric field in this region will remain unchanged, whatever change may take place in the external electric field. It follows from this that the intensity at each point of the region due to the surface distribution will be the same as that of the assumed electric field. As the potential in such a region is entirely determined by the surface potential distribution, which remains unchanged, it will be unaffected by any change in position or electrification of external bodies.

Also it is obvious from this principle that two or more regions, separated from one another by any number of surfaces, may each have a different electric field if, at every point of the dividing surfaces between any two of the regions, the fields in these regions have the same potential.

The truth of the principle just stated is almost self-evident, for it is known that, when the potentials of a system of conductors are given, there is only one possible solution of the electric field consistent with the given conditions. If, therefore, a solution be known that will give the same potential at each point of the bounding surfaces of a given region as the assigned

*Published in the Journal for February and March, 1918, pp. 36 and 77.

**The subject is more thoroughly covered in papers appearing in the 1913 *Transactions of the A.I.E.E.*, upon which a portion of the material in this Article is based:—"Air as an Insulator when in the Presence of Insulating Bodies of Higher Specific Inductive Capacity," by C. Fortescue and S. W. Farnsworth, Vol. XXXII, p. 893; and "The Application of a Theorem of Electrostatics to Insulation Problems," by C. Fortescue, Vol. XXXII, p. 907.

potentials, then this must be the only possible solution. It is not so easy to see that the field within the region is independent of any external influences. This may be deduced from the fact that, in order to produce a given potential at each point of the surfaces, (with the potentials at the surfaces assumed constant) the effect of external bodies within the region must be zero. Changes in the external electric field have the effect, however, of altering the charges at each point of the surface. In other words, the effect of any change in the external system is to produce a change in the capacity of the system of charged bodies at the surfaces of the region, in such a way that there is a change in the surface charges (the potentials remaining constant) of such a nature as to completely annul, within the region, the effect of the change in the external system.

Of course, in this particular discussion air and porcelain are the dielectrics considered. The breakdown strength of air between metal terminals of different sizes and shapes, when expressed in kilovolts per unit distance of separation, is a variable value and of little significance. The variation is due to the influence of such factors as the shape and size of the electrodes, and the position and potential of the electrodes relative to neighboring bodies, and not to differences in the strength of air, which is a physical constant. The case of comparative breakdown distances between spheres or needle points furnishes an excellent illustration. With 25 centimeters between spheres 25 cm. (10 in.) in diameter, air breaks down at 260 000 volts, whereas with the same voltage between needle points a separation of 67.3 cm. (26.5 in.) is required. The maximum efficiency of air has been determined by various investigators as ranging between 30 and 38 kilovolts per centimeter.

Of course, in the design of insulators, the problem is complicated by the presence of other dielectric media having a higher specific inductive capacity than that of air. There is, in general a false conception of the parts played by the two media, namely, the solid dielectric and air, in performing their functions in the insulator. With increased voltage, the part the air plays becomes more and more important. While the breakdown voltage of air alone, as expressed in volts per cm., is a quite variable quantity, the breakdown voltage of air over the surface of a solid dielectric when expressed in the same terms (a value commonly called "creepage" voltage) is still more variable.

As there are ways, as illustrated by the sphere gap, of using air alone more efficiently then is ordinarily done, so there are ways of using the combination of air and a solid dielectric more efficiently. The following discussion shows the conditions that determine the disruptive strength of an air path along the surface of a solid dielectric of higher specific inductive capacity and what steps must be taken to insure the most efficient use of the two dielectrics in combination.

THE ELECTRIC FIELD IN THE PRESENCE OF SOLID DIELECTRICS

The effect of introducing an insulating body into the static field between two conductors is to increase the stress in the air path at the surface of the conductor and at the surface of the insulating body, unless certain laws, which will be stated later, governing the proper shaping of the body are observed. This statement may easily be verified experimentally, by placing a glass sphere in an electrostatic field between two parallel plates maintained at different potentials. If the static field is intense enough, the introduction of the sphere will cause corona to form at the surface of the sphere and at the contiguous parts of the two plates. Consequently the air between the plates will break down at a much lower voltage than if the glass sphere were absent. The condition of the static field before the introduction of the glass ball is shown in Fig. 1, while Fig. 2 gives an idea of the field after the glass ball has been introduced. The lines of force concentrate on the glass ball and are more dense at its surface and at the portion of the surface of the two plates nearest the ball than anywhere else.

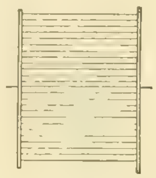


FIG. 1 — UNIFORM STATIC FIELD BETWEEN TWO PLATES

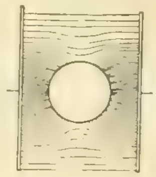


FIG. 2—STATIC FIELD WITH GLASS BALL INTRODUCED

A close analogy to the action which takes place when the glass sphere is introduced into the electric field is obtained by placing a steel ball in the magnetic field between two large magnetic poles of opposite polarity. In this case the field may be mapped out with iron filings.

There are several methods of determing the direction of electrostatic field and its equipotential surfaces experimentally as follows:—

a—Directly calculate by the process of cut and try. This method is theoretically possible but is laborious for any but the simplest shapes.

b—Obtain experimentally the isothermal surfaces in the related heat flow problem. The radiation and conduction of heat and the difficulty entailed in the obtaining of bodies of the proper heat conductivity make this method rather impractical.

c—Determine the equipotential surfaces in the equivalent electrical conduction problem.

d—Determine the direction of the electrostatic field under application of usual working voltage by means of dielectric particles, such as asbestos, etc.

Of course, methods *b* and *c* necessitate the use of materials other than the commercial porcelain. Method *d* is obviously rather approximate but the designs investigated may be made of the same material as the commercial insulators. During the investigations discussed methods *c* and *d* were both used.

The conditions that exist at the surface of a dielectric of high specific inductive capacity in a field of force

in air are brought about as follows:—A given difference of potential will cause a much greater electric flux in the solid dielectric than in the air. At the surface of separation of the air and the solid, the tangential component of the intensity must be the same in the air as in the solid. Since it requires *K* times the force to produce the same dielectric flux in the air as in the solid, where *K* is the value of the specific inductive capacity of the solid dielectric, the component of intensity in the air normal to the surface will be *K* times that in the solid dielectric. The intensity at each point of the surface of separation is increased from what it was before the introduction of the dielectric and is more nearly normal to the surface. If the solid body extends from one conductor to the other, a condition may be produced in which the tangential component of the intensity will be nearly uniform, but the maximum intensity, being in a direction more nearly normal to the surface than before the introduction of the solid, is greater at every

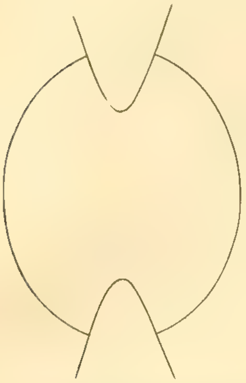


FIG. 3—EXPERIMENTAL INSULATOR
Whose outline follows the electrostatic lines of force.

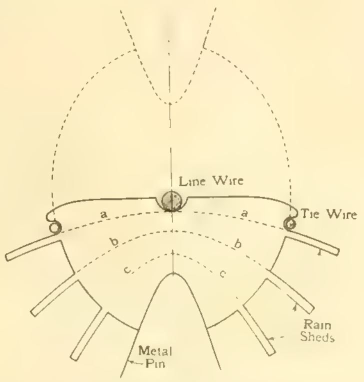


FIG. 4—DIAGRAM OF LINE INSULATOR
Whose outline similarly follows the lines of force.

point. The air path along the surface is, therefore, weaker than before the introduction of the dielectric. If, however, the dielectric is so formed that its surface is tangential to the lines of force at every point, then there will be no normal component of intensity; the tangential intensity at each point of the surface will be the same as before the introduction of the solid and the strength of the air path will remain unchanged.

In Fig. 3 is shown a design using a confocal system of ellipsoids and hyperboloids of revolution having foci which are 5.09 cm. (2 in.) apart. A piece was turned out of hard rubber to the given dimensions and the average breakdowns over the surface were above 160 000 volts, thus giving an average of 9.4 kilovolts per cm. (23 900 volts per in.) for a surface distance of 17 cm. (6.7 in.) These values are striking when compared with the breakdown voltage of usual line insulators. This piece was then placed where it would collect dust and dirt such as it would be likely to in indoor service and was tested after three months. It showed no deterioration in breakdown strength, even with this heavy coating of dust.

In the design of a transmission line insulator the first question that arises is "What is its function"? Of course, the function of an insulator is to prevent a loss of electrical energy by conduction between wires, from wire to ground, etc. Because of the stresses from wire tension, wind, etc., the insulator should be a good mechanical support. From mechanical consideration it is advantageous to keep the line wire and the pin close together and hence a material having a higher dielectric strength than air such as porcelain, is advantageous.

From a consideration of the elements of design it is obvious that the most satisfactory line insulator consists of an air insulator rather than of a porcelain insulator. That is, the porcelain under electrical stress, if the proper limitations of dielectric strength are assumed, can easily be made sufficiently thick to resist puncture. The problem is to shape the air path so that the flashover voltage will be sufficient under all service conditions. As a matter of fact the principles of theoretical design have been approached in certain cases by practical experience. The designing engineer has gradually changed certain designs by replacing highly stressed air sections with porcelain.

With these factors in mind the evolution of a pin type insulator design was attempted. A step in this evolution is illustrated in Fig. 4. The heavy solid line shows a pin type insulator roughly sketched from a consideration of the electrostatic field. The dotted outline shows a design similar to Fig. 3. Lines *aa, bb,* etc. are in equipotential planes. The rain sheds added to the porcelain surface conform to the equipotential planes and are relatively thin as compared to the length of the porcelain surface in the direction of the electrostatic flow lines. In general, the porcelain body has been added so that the surface of contact between the air and porcelain conforms to the equipotential planes or to the direction of the dielectric field.

SUMMARY AND CONCLUSIONS

From a theoretical standpoint, a conception was formed of the functions which air and solid dielectrics perform when used in combination for insulating purposes. Based on this conception, a large number of tests have been made under commercial conditions, which show that it is possible to use air more efficiently than has been customary in the past. Breakdowns of an air path over a surface have been obtained which average as high as 9.4 kv. per cm. effective value, (23 900 volts per in.) over a distance of 17.0 cm. (6.7 in.) The conditions of design are such that these same averages may be maintained at any voltage by increasing all dimensions of the structure proportionately.

A maximum efficiency of air path over a surface is obtained when the surface of the dielectric is made to conform to the flow lines between the terminals. The strength of such a path is independent of the specific inductive capacity of the dielectric. The principal thing to be considered, therefore, is the proper shaping of the terminals in order that points of high intensity may be eliminated and a high average intensity obtained for the given path.

Alternating-Current Generator Wave Form

F. D. Newbury and S. L. Henderson

THE FORM of the voltage wave of an alternating-current generator is determined mainly by the arrangement and connections of the armature winding, by the distribution of flux in the air-gap, and finally by the shape and relative value of the armature reaction. The first two factors determine the wave form at no load and the third determines the change in wave form caused by the load current.

If the armature winding were concentrated in one coil of full pitch then the voltage wave form would be determined entirely by the shape of the flux in the air-gap, or "field form," as it is commonly called. If, on the other hand, there are a number of armature coils connected in series and covering an appreciable part of the armature surface corresponding to one pole pitch, the voltage wave form is, for most practical purposes, independent of the field form. Obviously, the latter

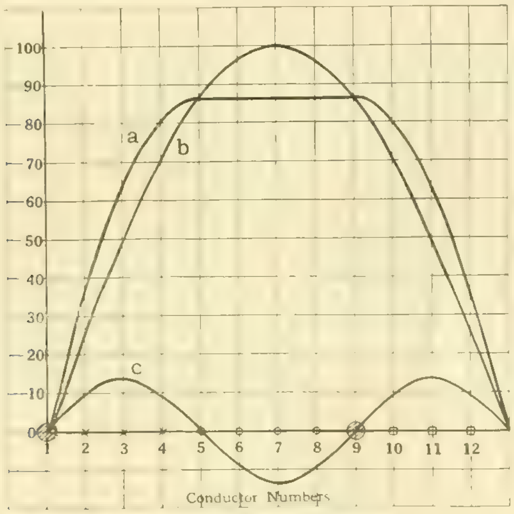


FIG. 1—FIELD FORM CURVES

a—Typical alternator field form.

b and *c*—The fundamental and triple harmonic of which *a* is composed.

condition is the one that applies to alternators of usual types, and the first factor, mentioned above, is the most important in determining wave form.

The voltage induced in a moving conductor at any instant is proportional, among other things, to the strength of the field in which it is located; that is, it is proportional to the ordinate of the field form in line with it. The instantaneous voltage induced in any number of conductors is the algebraic sum of the ordinates of the field form in line with the several conductors. Thus in Fig. 1, conductor *1* has zero voltage generated in it in the armature position shown. If the armature is assumed to move to the right, an angle of 15 degrees (equivalent to one armature slot), conductor *1* has moved to the position of conductor *2* (Fig. 1) and will have a voltage proportional to the field form ordinate, or 36*. The effect of various arrangements of armature conductors on the wave form can be investigated by this simple method, using the field form *a* of Fig. 1. Curve *1* of Fig. 2 is the wave form of conductor *1*, doubled. This wave form and the field form are identical in shape. Curve *2* is the wave form of conductors *1* and *2* connected in series; curve *3* of conductors *1* and *3*; curve 4 of conductors *1* and *4* and so on. In every case there are two conductors in series (or the equivalent as in curve *1*) and the only varying condition is the spread of the pair of conductors. In these various cases it is assumed that the coils have a throw or span equal to the pole pitch so that the other sides of the coils occupy the same relative positions under the adjacent pole, and may be neglected in determining the shape of the wave form.

The various wave forms gradually lose the flat-topped shape of the field form until, with the particular

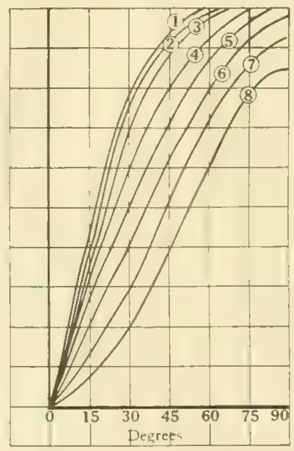


FIG. 2—WAVE FORMS OF TWO CONDUCTORS IN SERIES

field form selected, the wave form of conductors *1* and *5* is a sine curve. When the conductors are more widely separated, the wave form becomes more peaked than the sine and has a lower maximum value. Field form *a* is purposely drawn to be the resultant of the sine curve *b* and the sine curve *c*, having three times the frequency of *b*.

Curve *a* is quite closely the field form that would be obtained with a cylindrical radial-slot turbo-rotor, although an actual field form would also contain harmonics other than the third. Practically all commercial types of generators have a flat-topped field form and contain a large third harmonic that will appear in the voltage wave form for certain coil groupings. The voltage of any combination of conductors will be proportional to the sum of the ordinates of curves *b* and *c*. With conductors *1* and *5*, the voltage due to curve *c* is zero since positive ordinates of conductor *1* are balanced by negative ordinates of conductor *5* and the result is a voltage wave due only to the sine field form *b*.

Referring again to Fig. 1, conductors *1*, *2*, *3* and *4* of each pole would be connected together to form one

*This method of calculation was first developed by Mr. B. G. Lamme about 1894 and is quite generally used by designing engineers whose training has been directly or indirectly influenced by Mr. Lamme's work.

leg of a three-phase Y-connected winding, (neutral to terminal), and conductors *1* to *8* would form one phase (terminal to terminal). It is assumed that the two sides of each coil are one pole pitch apart. If the wave form of conductors *1*, *2*, *3* and *4* is calculated it will be found to contain a large third harmonic, but the wave form of the conductors *1* to *8* inclusive will be found to contain no third harmonic. The reason for

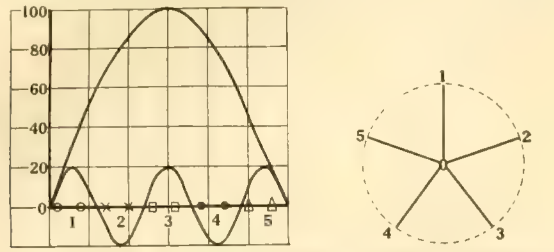


FIG. 3—A WAVE FORM CONTAINING A FIFTH HARMONIC

this is that the third harmonic voltage in each conductor of the group *1* to *4* is opposed by an equal and opposite third harmonic voltage in one of the conductors of the group *5* to *8*. For example, the third harmonic voltage generated in conductor *1* is neutralized by that in conductor *5*; the third harmonic in conductor *2* is neutralized by that in conductor *6*; etc. Thus in the voltage wave of a leg of a three-phase winding, there is a considerable part of whatever third harmonic that exists in the field form; but with the phase voltage star-connected the third harmonic is eliminated.

If such a thing as a five-phase machine existed, it would be found, referring to Fig. 3, that the voltage across terminals *1* and *2* or any similar pair of legs would contain no fifth harmonic, because the fifth harmonic in each conductor of group *1* is opposed by an equal and opposite fifth harmonic voltage in group *2*.

In three-phase Y-connected alternators with neutrals paralleled, the third harmonic and multiples thereof are present in the circuits connected together and these cases require additional care for this reason. It has been explained why the third harmonic appears in the leg voltage of Y-connected windings. Unless the generators are of the same design, it is probable

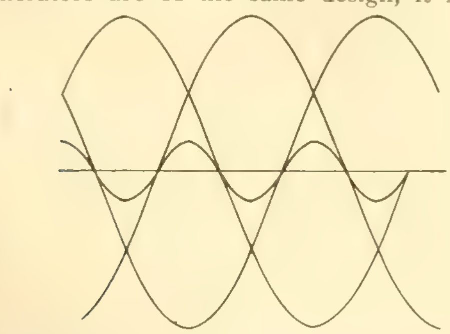


FIG. 4—THREE-PHASE FUNDAMENTAL AND TRIPLE HARMONIC WAVES

that the voltages from terminal to neutral will vary in the several generators, since the field forms are apt to vary much more than the phase-voltage wave forms. If these voltages vary, there will be circulating current in the neutral bus that may be objectionable. This difficulty may be avoided by connecting only one generator to the neutral bus, which will usually be sufficient. But if there is an appreciable divergence from the sine in the field form of the generator, with neutral connected to ground or to a neutral main in a four-wire distributing system, the generator will be more likely to cause telephone trouble than if the neutral were not brought out.

In a delta-connected armature, conductors *1* to *4* inclusive form the complete phase (terminal to terminal) and the third harmonic voltage will be present, for reasons already given, in the voltage of each separate phase.

The difficulty in connection with delta-wound alternators is one that concerns the designer only. The delta-wound armature is a closed series circuit within the generator. No normal frequency current flows in this closed circuit (unless current flows in the external circuit) because the three voltages are out of phase in such a relation that their sum is always zero. But this condition does not hold for the third harmonic or for multiples of the third. The third harmonic voltage, or any odd multiple of it in any phase, is in phase with the same frequency voltage in the other two

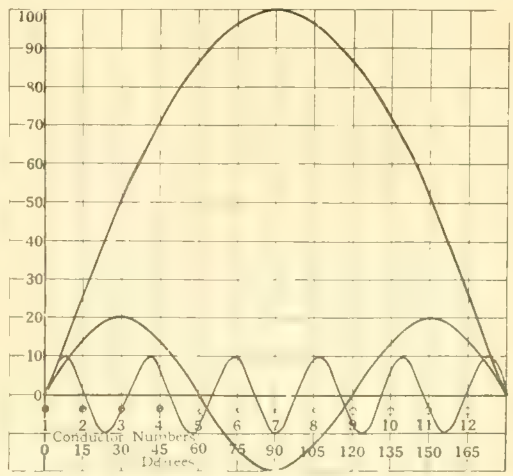


FIG. 5—FIELD FORM CONTAINING AN ELEVENTH HARMONIC OF TEN PERCENT

phases. Therefore, these higher frequency voltages are greatly augumented and circulate currents in the closed winding, that may cause objectionable heating. These phase relations of the fundamental and triple frequency three-phase voltages are shown in Fig. 4. These higher frequency voltages that exist in the separate legs of the winding will be consumed in circulating current in the closed delta and will not appear in the external circuit. This circulating third harmonic current not only increases the copper loss in the stator, but since it is a single-phase current, it also increases the losses in the rotor by circulating a sixth harmonic current in the pole faces or damper winding if there is one. That this is a sixth harmonic current follows from the fact that the magnetomotive force of the armature, due to the circulating third harmonic current, produces a reaction of three times the number of poles of the machine and is single-phase and is therefore a pulsating field. This field can be split up into two rotating fields each of the synchronous speed of the third harmonic,

one running in the same direction as the rotor and at the same speed, since it has three times the number of poles of the fundamental reaction, and one running opposite to the rotor and cutting the rotor at double the frequency of the third harmonic or six times the fundamental,

The field form in Fig. 1 represents a simple case since it can be resolved into the fundamental and only one harmonic sine curve. Any field form can be resolved into a number of sine components and what has been shown to be true in the case of the field form chosen is true in regard to the third harmonic component of any field form.

The number of slots per phase group, while not affecting the percentage magnitude of the third harmonic, and multiples of the third, may be quite effective in reducing the effect of other harmonic components of the field form. For instance, in Fig. 5 a field form is shown containing an eleventh harmonic of ten percent. For a three-phase winding with two slots per phase per pole there would be generated in coils *1* and *3* an eleventh harmonic voltage of ten percent. If the slots per phase per pole are increased to four, the eleventh harmonic, in the coils from terminal to neutral, is reduced to 1.3 percent and if there are six slots, the eleventh is reduced to 1.06 percent. If at the same time there was a third harmonic in the field form, there would be generated in the coils from terminal to neutral, a third harmonic of 7.07 percent, 6.54 percent and 6.46 percent for the respective combinations, thus showing very little difference in the third harmonic voltage for the different groupings. In Fig. 5 it is seen that with two slots per pole per phase (conductors *1* and *3*) the slots are so placed with respect to the eleventh harmonic that the voltages add. When, however, more slots are added, some of the slots are generating voltages in opposite directions and consequently the harmonic voltage is decreased. With reference to the third harmonic voltage, the phase span of the coils is equal to the span of the third harmonic and adding more slots does not introduce any negative components tending to decrease the third harmonic voltage.*

The statement is often made that even harmonics never appear in the wave form if, as is usually the case, north and south poles are identical. Fig. 6 illustrates this condition. It is evident that there can be no even harmonics in the field form unless each field is unsymmetrical and also unless adjacent fields are different in shape. Neither of these conditions exist unless the field structure is unsymmetrical. If, however, due to such construction, the field form did contain even harmonics, they still would not appear in any voltage wave if the winding were pitch as in coil 4-4. With this arrangement it is seen that the voltage generated by any even harmonic flux in one side of the coil is neutralized by an equal and opposing voltage generated in the other side of the same coil.

If, with the field form of Fig. 1, the armature coils, instead of having a throw of slot *1* to slot *13*, have a shorter throw of slot *1* to slot *9* or two thirds of full pitch, there will be no third harmonic in any combination of conductors since there will be an equal and opposite voltage generated in the two sides of each coil by the third harmonic component of the field form. Thus chording is in many cases an important means of improving wave form. There is one value of chording that will completely eliminate any given harmonic. It has been shown that a two thirds chord ratio will eliminate the third harmonic; similarly a four-fifths ratio will eliminate the fifth harmonic and a six-sevenths ratio will eliminate the seventh harmonic.*

It is not always possible, of course, to obtain the

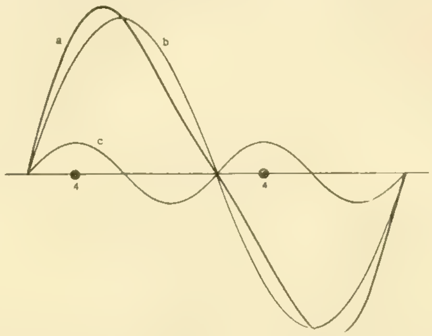


FIG. 6—TYPICAL WAVE FORM (a), CONSISTING OF THE FUNDAMENTAL (b) PLUS A THIRD HARMONIC (c)

*This phenomenon has been mathematically treated by Smith & Bolding in the February 1915 issue of the *Journal of Institution of Electrical Engineers* (British) and they have found that any harmonic in the field form will be reproduced in the phase voltage provided that $2ns \pm 1$ equals the degree of the harmonic, where $n =$ the integers *1, 2, 3*, etc., and $s =$ slots per pole. All other harmonics will only exist to a negligible extent with the exception of the third harmonic and multiples of the third corresponding to $2ns \pm 3$. The magnitude of the third and multiples of the third is practically constant irrespective of the number of slots and ranges between 60 and 70 percent of their value in the field form.

*A general expression for the ratio of generated voltage with a short pitch winding to the voltage of any frequency that would be generated with a full pitch winding is:—

$$\textit{Ratio (or chord factor)} = \sin n\left(\frac{\pi}{2} \times \frac{t}{s}\right)$$

where:—$n =$ order of harmonic (for the fundamental $n = 1$); $t =$ slots throw; and $s =$ slots per pole.

Thus, with a throw two-thirds of full pitch the chord factor for the third harmonic is:—

$$\sin 3\left(\frac{\pi}{2} \times \frac{2}{3}\right) \text{ or } \sin \pi = \text{zero.}$$

As an interesting example of a value of chording that is very effective from the standpoint of good wave form, consider a winding having a throw of 10 slots in an armature having 12 slots per pole; that is, a chording five-sixths of full pitch. Using the above general expression, there is obtained at each frequency, the following ratio of the voltage generated in the chorded winding to the voltage which would be generated were the winding full pitch.

Fundamental	0.966
3rd harmonic	0.707
5th harmonic	0.258
7th harmonic	0.258
9th harmonic	0.707
11th harmonic	0.966
13th harmonic	0.966
15th harmonic	0.707
17th harmonic	0.258
19th harmonic	0.258

If this generator were three-phase star-connected, the third and multiples of the third harmonic would be eliminated from the phase voltage, the fifth, seventh, seventeenth and nineteenth would be reduced to one-quarter of the value they would have with a pitch winding and only the eleventh and thirteenth would appear at approximately full value.

throw most desirable for reducing harmonics in the voltage wave. To obtain a throw of four-fifths the armature must have 15 or 30 slots per pole and a throw of six-sevenths requires an armature of 21 slots per pole, and these large numbers of slots are seldom feasible except in turbogenerators having two or four poles.

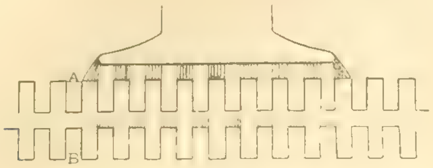


FIG 7

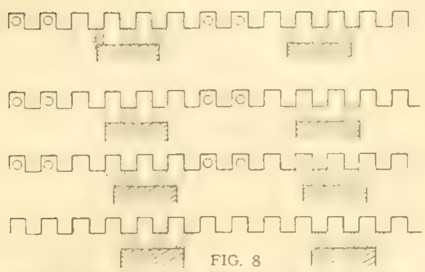


FIG. 8

FIGS. 7 AND 8—THE EFFECT OF TOOTH FLUX

It has already been pointed out that, in a delta-connected armature, the third harmonics are present in each phase and will cause a circulating third harmonic current inside the delta. This third harmonic voltage can be eliminated by the expedient of the two-thirds chord just described.

In the preceding discussion, the effect of open slots on the field form and voltage wave form is neglected. With a large ratio between width of slot and length of air-gap, open slots may cause higher harmonics due to a cyclic variation of the reluctance of the air-gap path and by a shifting of the flux back and forth across the pole.

In Fig. 7 is shown one pole of an alternator with twelve slots per pole in the armature. At the instant shown at *A* there are seven teeth under the pole and at instant *B* eight teeth. This then causes the total flux to pulsate between a maximum and a minimum at a frequency equal to the number of slots per pair of poles. This will usually be an even pulsation in the nature of 12, 18 or 24 times normal frequency. As every stationary pulsating field can be considered as the resultant of

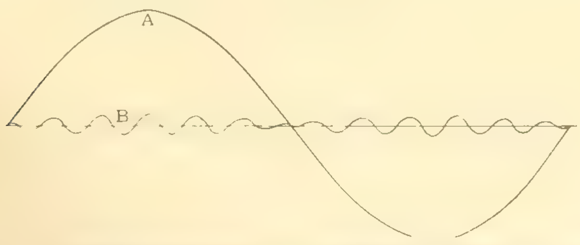


FIG. 9—HARMONIC VOLTAGE IN A GENERATOR HAVING 12 SLOTS PER POLE

two fields of constant value rotating in opposite directions, there will result one field rotating against the direction of rotation of the rotor and one with, which will generate in the armature winding two voltages, one at a frequency corresponding to twice the number of slots per pole plus one; and the other at a frequency corresponding to twice the number of slots per pole minus one.

The harmonics set up by a variation of the air-gap reluctance is seldom of much moment as the flux must pulsate in the entire magnetic circuit, and as there is usually some solid iron in this path, such as the yoke and the spider, eddy currents are generated in these parts which damp out this pulsation. The tendency to pulsate is also reduced by fringing to the teeth not directly under the pole. In Fig. 7 for instance, the pulsation would not be between the limits expressed by the reluctance of seven teeth and eight teeth, but between seven plus a large fringe and eight plus a smaller fringe.

The generation of harmonics by a swinging or sliding of the flux across the pole is generally of more importance than the pulsation due to a change in the total reluctance. In Fig. 8 are shown several positions of the armature, the first being in the position of zero voltage and with the flux evenly distributed over the pole; that is, just as much flux on the right side as the left. As the armature rotates, the flux first bunches up to the right hand side and then later slides back and piles up on the left hand side. There results therefore a period when the voltage is generated at a faster rate than by

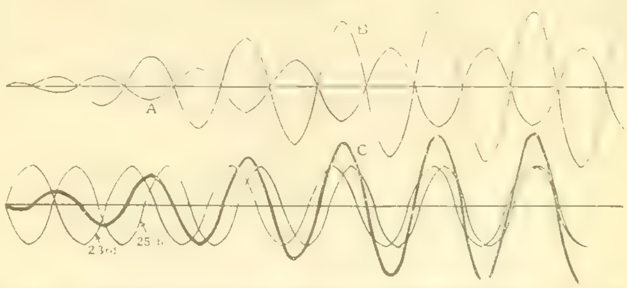


FIG. 10—HARMONIC VOLTAGE DUE TO DAMPER SLOTS IN THE POLE FACE

rotation and then at a slower rate. In Fig. 9 is shown such a voltage generation by a machine with twelve slots per pole, assuming sine wave flux distribution. It will be noted that the amplitude of the harmonic voltages decreases, owing to the fact that the amplitude of the main flux decreases correspondingly and therefore does not generate as much voltage as when the phase group is in the center of the pole. The magnitude of these harmonics can be reduced by making the ratio of air-gap to slot opening high, by using closed slots, skewing the slots, or skewing the poles, although the last two methods present mechanical difficulties which make it impossible to apply except on small machines or for experimental work.

The harmonic voltage appearing here will also be equal to two times the slots per pole ± 1. In connection with the generation of harmonics by flux swinging and by the selective action of the armature when harmonics exist in the main field form, it is not evident at once that an even number of slots per pair of poles or an even number of damper slots in the field will produce odd harmonics. Even in examining the voltage wave form on an oscillogram one would be led to believe that there existed an even harmonic. In Fig. 9

there is represented a harmonic voltage due to a swinging flux and in Fig. 10, a harmonic voltage due to damper slots in the field equal to twelve with twelve slots per pole in the stator. In each of these cases the spacing of the ripples and the number would indicate a twenty-fourth harmonic. It should be noted, however, that the amplitude of the ripples is varying, which cannot be detected on the oscillogram, and also that the ripple is unsymmetrical near zero of the voltage wave.

Referring to Fig. 10 (and the same argument will hold for Fig. 6) *A* represents the ripple in the flux wave, *B* the voltage generated by a group of four conductors in this harmonic flux. It would appear that this represented a twenty-fourth harmonic voltage. In the lower part of Fig. 10 is a diagram showing a twenty-third and twenty-fifth harmonic, each of half the magnitude of the maximum ripple in *B* and also the sum of the twenty-third and twenty-fifth shown as *C* and this is seen to be an exact duplicate of *B*. Therefore the true harmonic voltages are the twenty-third and twenty-fifth, which equal twice the number of slots per pole ± 1.

A field form and voltage wave form is shown in Fig. 11 on a machine which has eight damper slots spaced as eleven in the field, and six slots per pole in the stator. According to the rule, there could be an

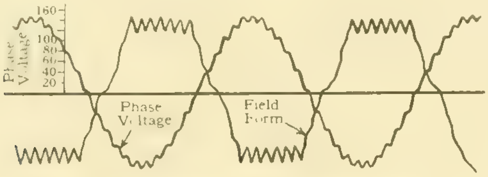


FIG. 11—EFFECT ON THE WAVE FORM

Of eight damper slots in the pole face and six per pole in the stator.

eleventh or thirteenth harmonic due to the stator slots or a twenty-first or twenty-third due to the damper slots. The field form shows that the damper slots do produce a ripple and the voltage wave form shows a twenty-third harmonic, so that the biggest factor for producing the harmonic voltage is the fact that the slots per pair of poles plus two in the field is a multiple of the slots per pair of poles in the stator.

The wave form obtained from a loaded alternator usually differs from that of an unloaded machine on account of the effect of armature reaction. The effect of the armature reaction flux is to distort the main field and shift it in the direction of motion (relative) of the armature conductors. Fig. 12 shows no-load and the load waves at rated current and 80 percent power-factor. The distortion and shift noticeable in Fig. 12 will be absent with zero power-factor lagging or leading since the main and armature fields are then in phase or in phase opposition. The effect of load on wave form in the single-phase alternator will be nearly the same as in the polyphase alternator providing the field has a suitable damping winding. The pulsating nature of the armature field, which is never completely changed by the cage winding, tends to make the load wave form of single-phase alternators depart from the no-load wave to a greater extent than in polyphase alternators.

In the majority of cases the wave form obtained with ordinary design proportions and types of construction is well within the limit of 10 percent variation from the sine approved by the A. I. E. E. standardization rules and for the majority of alternator applications this standard satisfactorily meets the conditions. Special applications of alternators sometime require much closer approach to the sine and these cases demand special attention on the part of the designer. The most important cases of this kind are:—

a—Alternators connected to transmission lines that parallel telephone lines for considerable distances.

b—Three-phase Y-connected alternators operated with neutrals connected in parallel, as in three-phase four-wire distribution.

c—Three-phase alternators with delta-connected armature windings.

d—Alternators used for cable testing or for experimental work requiring a sine voltage.

From the stand-point of inductive interference with paralleling telephone lines, the higher harmonics are those to be avoided. The telephone receiver is most

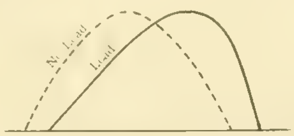


FIG. 12—TYPICAL NO-LOAD WAVE AND FULL-LOAD 80 PERCENT POWER-FACTOR WAVE

sensitive to frequencies in the neighborhood of 1100 cycles per second or to the fifteenth to the twenty-third harmonics in sixty cycle generators. Since nine to fifteen slots per pole are commonly used in the larger alternators, trouble from tooth ripples may be experienced unless the designer takes precautions to obtain good proportions between slot opening and air-gap (particularly necessary in alternators wound for high voltage) and to obtain the best arrangement of the armature winding. This is usually not difficult in the larger alternators used for power transmission and such machines are usually specially designed to meet the purchasers requirements so that the necessary precautions can be taken. In the smaller machines, and particularly in those wound for high voltages (in which wide slots are necessary) and those directly connected to low-speed engines or water wheels (in which the air-gaps are normally relatively small) and when insurance against telephone interference is necessary, a considerable increase in first cost may be involved.

The Oscillating Phase Advancer

C. W. KINCAID
Industrial Engineering Dept.,
Westinghouse Electric & Mfg. Company

OSCILLATING phase advancers are used in connection with wound-rotor induction motors to increase the power-factor of the current taken from the line by the motor. They are distinguished from other types of phase advancers in that they do not rotate continuously in the same direction, but rotate only a few revolutions in one direction before they reverse and rotate in the opposite direction. The frequency of reversals is dependent on the frequency of the current supplied by the rotor of the induction motor in whose circuit they are connected.

In its elementary form such a phase advancer consists of a permanent bar magnet suspended, as shown in Fig. 1, inside an iron ring, on which is a field winding so placed as to produce a flux in the direction *XX* when excited with direct current. The bar magnet is constrained to a normal or zero position along the axis *YY*, this directing force being negligible in comparison with the force exerted by the winding. Then a low frequency alternating current in the winding will set the bar magnet into oscillation about its zero position, whereby an interaction is set up between the alternating-current and the inertia of the oscillating magnet. The angle of oscillation depends upon the mass of the magnet which, with a bar magnet, must be such that the oscillation is less than 180 degrees.

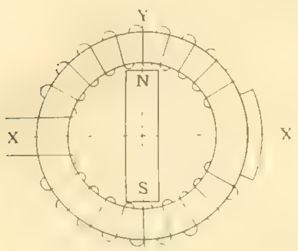


FIG. 1—ELEMENTAL OSCILLATING PHASE ADVANCER

On account of the limited angle of oscillation, the mass of the magnet necessary to produce a given result would, in this elementary form, be so great that the phase advancer would be inefficient. In actual practice the relative positions of the elements are interchanged in order to allow an angle of oscillation greater than 180 mechanical degrees, with corresponding mass reduction of the vibrating element, the magnet being made stationary, in which case its weight is immaterial, and the exciting winding being placed on the oscillating element and provided with a commutator.

These machines thus resemble two-pole direct-current machines but are different in general proportions from standard direct-current motors. They must be separately excited, as the field required is constant, the same as in direct-current motors, whereas low-frequency alternating current is applied to the armature.

INDUCTION MOTOR CHARACTERISTICS

In order to understand what characteristics the phase advancer must have to give the desired effect on the induction motor, some of the fundamental principles of the induction motor will be reviewed.

The field of an induction motor is set up by the same winding that carries the load current, but the current which produces the field is 90 electrical degrees out of phase with the load current. (By load current is meant that current which is in phase with the counter e.m.f. of the motor and is proportional to the motor input). The combination of the load current with the magnetizing and leakage currents at right angles is a measure of the power-factor of the motor; the power-factor being low when the magnetizing current is a large percentage of the load current and high when the percent magnetizing current is low. If in a given motor the magnetizing current could be decreased, the power-factor at all loads would be increased, becoming 100 percent if all the wattless component of current could be eliminated.

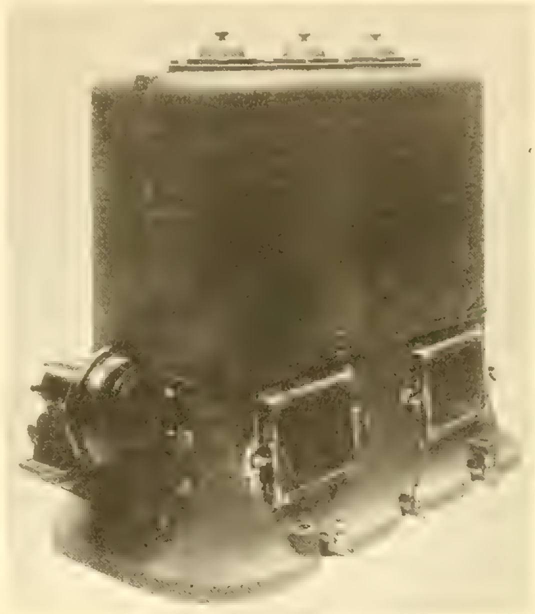


FIG. 2—OSCILLATING PHASE ADVANCER
For raising the power-factor of a 2600 hp, 81 r.p.m. motor from 84 to 98 percent.

Suppose in a wound rotor induction motor only the load current be allowed to flow in the primary winding. The power-factor of this current is 100 percent, which is just what is wanted, but there is no magnetizing current to produce a field against which the load current could react to produce torque. In other words it is a motor without a field. Since this motor has a phase wound rotor the lacking part, the field, could be supplied by applying the correct value of current at the right frequency and phase displacement to the collector rings. The ampere-turns required will agree with the wattless ampere-turns taken from the line when operating as a straight induction motor, and will be in the same phase relation with the counter e.m.f. of the primary, i.e. lagging 90 degrees. The frequency of the magnetizing current supplied to the rotor will be equal to the percent slip of the motor times the line frequency, being line frequency when the motor is at

standstill, and zero or direct current when the motor is at synchronous speed.

The reactance of the primary and secondary of an induction motor are approximately equal, so that the voltage required to send a certain current through either rotor or stator would be the same if the frequencies were the same. (A one to one ratio is assumed). But the frequency in the rotor is proportional to the slip of the motor, being one-half line frequency at one-half speed or 50 percent slip, and full line frequency at zero speed or 100 percent slip, so that the voltage required to force the magnetizing current through the rotor winding would be proportional to the slip of the motor. Hence the volt amperes required to magnetize an induction motor from the rotor winding would depend on the slip of the motor, and at normal full speed might be approximately two to five percent of the volt amperes required if the magnetizing current was supplied from the primary winding at full frequency and line voltage.

THE PHASE ADVANCER

It is known that if a very low frequency voltage is applied to the armature of a separately-excited direct-current motor, the armature will accelerate in one direction, decelerate and repeat the action in the opposite direction, passing through zero speed twice each cycle or once each alternation. When the current passes through zero, it has changed its direction in the armature and changes from an accelerating force which increases the speed, to a regenerative or braking force which decreases the speed. From this it is evident that the speed has reached a maximum value when the current is passing through zero. From its zero value the current, and with it the braking force, increases according to the sine law and brings the rotor to rest just as the current reaches its maximum value. The current, as it decreases from the maximum value to zero, accelerates the rotor to its maximum speed in the opposite direction.

Since the current is maximum when the speed is zero and the speed is maximum when the current is zero, the speed and current are in quadrature. The rotation will induce a voltage in phase with it and since the speed and current are in quadrature, the induced voltage and induced current are in quadrature with the load current which accelerates the rotor. This shows that the induced current is in quadrature with the load current, but does not show whether it is lagging or leading.

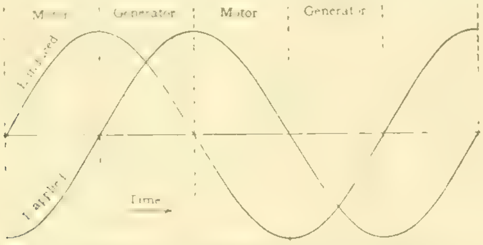


FIG. 3—WAVES OF INDUCED AND APPLIED E.M.F.

This machine acts as a motor when the speed is being increased, i.e. when it is receiving energy and storing it. It acts as a generator when the stored energy is being given out to produce the quadrature k.v.a. When a machine is acting as a motor, the induced e.m.f. of the armature opposes the applied voltage, while as a generator the induced e.m.f. is in the same direction as the terminal e.m.f.

This induced e.m.f. and the applied e.m.f., i.e. the voltage to force the load current through the armature, are plotted with respect to time, making both curves positive when the machine is acting as a generator as explained above, in Fig. 3. In this figure the induced voltage is at its maximum value 90 degrees before the applied voltage reaches its maximum value, showing that the induced voltage and consequently the induced current will be leading with respect to the load current.

FIG. 4—INDUCTION MOTOR VECTOR DIAGRAM

These phase relations between current and speed tend to produce ideal commutation of the load current, because the speed is maximum when the current is zero and the speed is zero when the current and consequently the commutating field is maximum. The induced current is the only one that can cause much trouble, but these machines usually have one turn coils and almost always have induced voltages below 50 volts, so that the problem of commutation is not a serious one. The machine shown in Fig. 2 showed practically no sparking even during overloads.

In Fig. 4 is shown part of the vector diagram of an induction motor, E_p being the primary e.m.f., E_s being the secondary induced e.m.f. and I_m being the magnetizing current in phase with the field flux, both the current and the flux being at right angles to the voltages. The magnetizing current is always 90 degrees lagging with respect to the primary e.m.f. when acting as a plain induction motor, and since the secondary induced e.m.f. is 180 degrees away from the primary, the magnetizing current is 90 degrees leading with respect to the secondary e.m.f. This shows that the leading current produced by the phase advancer is of the correct frequency, and bears the correct phase relation with the primary e.m.f. to magnetize the motor. If the motor is magnetized from the rotor, no magnetizing current will be required from the line and consequently the power-factor of the motor will be made higher.

The inertia and number of conductors of the phase advancer are therefore so proportioned that it will attain a certain speed and thus generate enough voltage to send the desired magnetizing current through the rotor windings. The speed which any such armature will attain, depends on the current supplied to it by the rotor of the induction motor. The more current supplied, the higher will be the speed and induced voltage, and since the current supplied depends on the load on the induction motor, the phase advancer will have a higher voltage and give a greater corrective effect under load than with practically no load.

At no load there will not be enough current through the phase advancer to make it oscillate, so that at no load the power-factor may be reduced slightly due to the added reactance in the rotor circuit. As the current in the rotor increases, due to the load, the phase advancer will begin to oscillate and the maximum speed attained will increase as the load is increased until the time between oscillations becomes so short, due to the increased slip and rotor frequency, that the increased torque due to the increasing load current will be counterbalanced by the decreased time in which the rotor has to accelerate. Therefore with any certain induction motor and phase advancer, there is a point of maximum corrective k.v.a. beyond which an increase of current will give less correction.

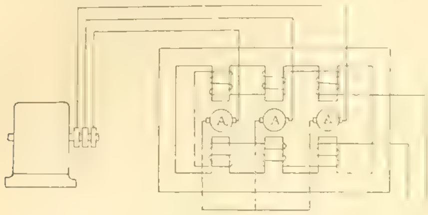


FIG. 5—CONNECTIONS OF PHASE ADVANCER TO MOTOR SECONDARY

The phase advancer also acts similar to a condenser in supplying a leading current in the rotor and this has the effect of increasing the pull out torque of the motor by decreasing its resultant reactance. The magnetizing k.v.a. which is used to magnetize the motor through the rotor as above, is taken from the line as a power component which is stored in the flywheel capacity of the rotor of the phase advancer and given out a quarter of a cycle later.

Most induction motors have three-phase rotor circuits and as the phase advancer is essentially a single-phase machine, three armatures will be required, one for each phase. These armatures may be in one frame, as shown in Figs. 2 and 5, or in separate frames, although having the three armatures in one frame makes the machine lighter and more easily handled. The armatures may be connected in star or delta, depending on the current to be handled. The star connection is used for the smaller sizes where the current per commutator is not large. When the current per commutator makes the commutator too long to build with the star connection, the armatures are put in delta, whereupon the current is decreased to 57 percent of its former value.

The voltage induced by an armature depends on the number of conductors in series on the armature, on the field strength, and on the velocity with which the armature rotates. The velocity depends on the field strength, the number of conductors, the current per conductor, and inversely on the time it has to get up speed before it begins to decelerate (i.e. the slip frequency $= sf$) and also inversely as the moment of inertia of the armature. The voltage induced, or the corrective action, depends directly on the load current per conductor, and on the square of both the flux per pole and the series conductors and inversely with both the slip frequency and the moment of inertia. This expressed in a formula is:—

$$e = \frac{k\ (\phi \times w)^2\ I}{sf \times mi}$$

Where e = volts induced; ϕ = flux per pole; w = series conductors; s = percent slip; f = line frequency; I = load current; mi = moment of inertia; k = constant.

The moment of inertia varies with the mass times the square of the radius of gyration, and since the mass varies with the volume and the radius of gyration is dependent on the diameter the moment of inertia varies with $D^2L \times D^2$ or D^4L. Hence the diameter affects the output as the fourth power and consequently is kept as small as possible. The voltage varies with the square of the flux and conductors so that these are made as large as possible. The flux being large and the diameter small, the length is increased in order to keep the densities low.

From these limitations, such machines will always have very long armatures and commutators. Ball bearing are used to decrease as far as possible the braking action of the bearings, while the small diameter of the commutator and armature tend to minimize brush friction and windage, which decrease the output of the machine. These machines are not good self-ventilators on account of their low average speed and because they do not rotate continuously in one direction. For this reason they are practically always built for forced ventilation.

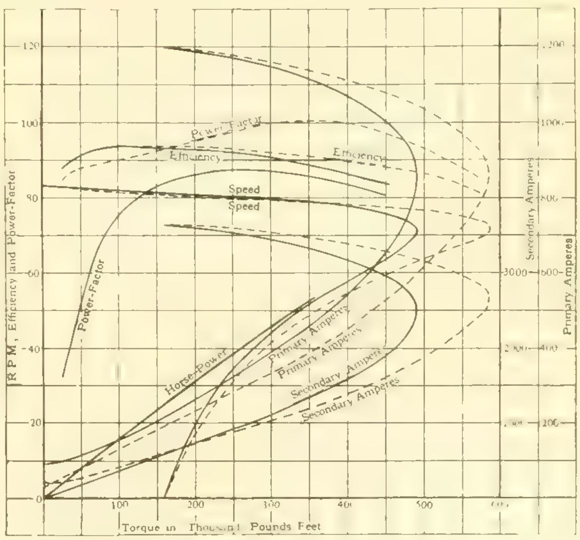


FIG. 6—PERFORMANCE CURVES OF 2600 HP, THREE-PHASE, 25 CYCLE, 36 POLE, 81 R.P.M. INDUCTION MOTOR

Solid lines—Motor alone.
Dotted lines—Motor with phase advancer.

Phase advancers of this type are limited to use with motors having a fairly low slip. In large machines, the slip frequency should not be much more than one cycle per second and in smaller machines it may run as high as one and one half cycles per second. For the same reason, these machines are more applicable to twenty-five cycle than to sixty cycle motors.

The Engineering Evolution of Electrical Apparatus-XXXIV

The Development of the Street Railway Motor in America

B. G. Lamme

EDISON SINGLE-REDUCTION MOTOR

The Sprague double-reduction motor was one of the best of its type, and persisted longest of any of this type. However, the Edison Company who had taken over the manufacture of the Sprague motor, finally recognized that the day of the double-reduction motor was past and a single-reduction motor was then gotten out. This was a steel frame four-pole motor. The armature was of comparatively large diameter and, according to the writer's memory, was of the surface-wound type. An attempt was made to retain some of the features of the Sprague double-reduction motor, by having commutated field coils, but due to the more highly saturated magnetic circuits, this was not very satisfactory. This motor had a comparatively short commercial life and it was evidently simply rushed into the market to meet the competition of other single-reduction motors.

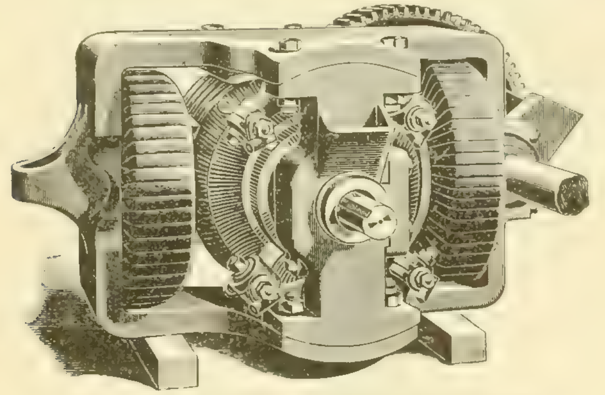


FIG. 8—EDISON SINGLE REDUCTION MOTOR 1891

THE SHORT SINGLE-REDUCTION MOTOR

Professor Short, early recognizing the trend of development, got out a single-reduction railway motor along lines somewhat similar to his former double-reduction. The principal difference was that this new motor was of a four-pole instead of two-pole type. The disc type of armature, with side poles, was retained along with most of the other characteristic features of the older motor. This motor attracted much attention, but as it possessed a number of fundamentally wrong features, such as a ring type of armature, danger from unbalanced side pull, etc., it was a type which was doomed to disappear eventually.

In this early period of the single-reduction motor, the belief was held, rather generally, that the ring-type railway armature was essentially superior to the drum-type. As the Westinghouse Company never put out anything but the drum-type railway armatures and as, at different stages in the early development, several of the competing companies used the ring-type, the writer was "hard put" at times to defend his company's practice. Many and long were the arguments which he had on this score. At one time it looked, to an outsider, as if the ring-type was capturing the field. This was when the Short single-reduction motor and the Thomson-Houston "WP" were the principal competitors of the Westinghouse single-reduction. Both the former motors had ring-type armatures against the Westinghouse drum-type. However, practical operation gradually developed the superiority of the drum-type and the use of machine-wound armature coils had much to do with deciding the problem, for unquestionably the machine-wound armature coil was much more applicable to the drum-type than to the ring. Moreover, there were inherent weaknesses in the ring-type, such as the use of non-magnetic spiders, methods of attaching the spider to the core, etc. In the light of present experience, it is surprising that the ring-type armature made as good showing as it did.

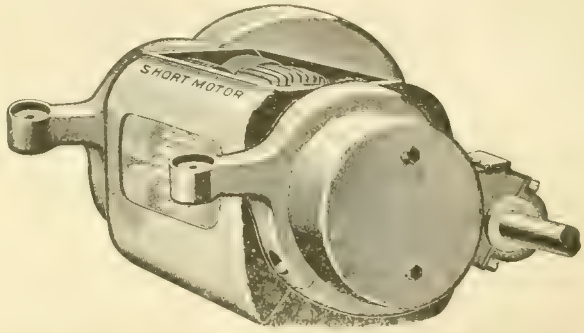


FIG. 9—SHORT SINGLE REDUCTION OR WATER TIGHT MOTOR

GEARLESS MOTORS

Following the success of the single-reduction motors, two of the companies, namely, the Westinghouse and the Short, attempted to make gearless motors along the same general lines as the single reduction type. The Westinghouse Company put out two constructions, one having four poles and the other having six, the latter being considerably lighter. However, both of these motors were too heavy and it soon developed that the gearless principle was not a satisfactory one for ordinary street car purposes, due largely to undue weight directly on the axle, and to the difficulty in removing an armature from the axle, in case it was necessary for repair purposes.

The Short Company built a gearless motor along the same lines as its single-reduction and tested it out in practice, but it was soon abandoned for the same general reason as the Westinghouse, namely, that the gear-

less principle was fundamentally incorrect for ordinary street railway service.

FURTHER DEVELOPMENTS OF SINGLE-REDUCTION MOTORS

As indicated, the Edison motor soon dropped out of the running. It contained nothing lasting in its type. Also, although it persisted longer than the Edison, the Short type gradually dropped out. Meanwhile the Edison and the Thomson-Houston Companies had combined and formed the General Electric Company. This company continued to develop its railway motors in the attempt to find something better than its W. P., already described. The Westinghouse Company also persisted in its development, principally with a view to reducing the size and weight of the No. 3 motor. The future development of the railway motors, therefore, lies almost entirely with these two companies.

The Walker Company, about 1895 or 1896, appeared on the market with a railway motor and did a very considerable amount of business until absorbed by the Westinghouse Company. The Lorain motor attracted considerable attention for a time, but was also taken over by the Westinghouse Company. Both of these were so nearly along the general lines of the Westinghouse, that they need not be considered as special types.

LATER TYPES OF WESTINGHOUSE MOTORS

After the No. 3 Westinghouse motor had proved to be commercially a very successful type, the writer turned his attention toward improvement in its general type without losing any of the more advantageous features. One of the features in the design of the No. 3

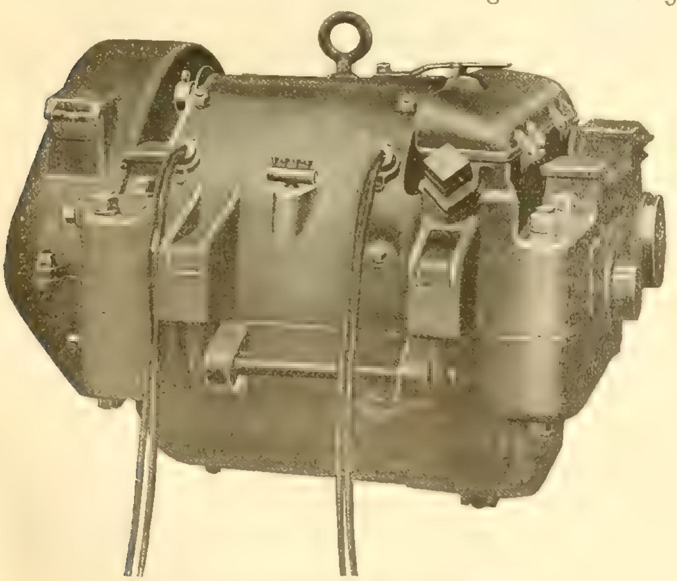


FIG. 10—WESTINGHOUSE NO. 12 MOTOR

was the use of as many slots in the armature as there were armature coils and commutator bars. This was supposed to give ideal magnetic symmetry and, therefore, was assumed to be the best possible arrangement. However, the writer in going over the magnetic principles and proportions of the motor, decided that by sacrificing magnetic symmetry to a certain extent, considerable gains could be made in reducing the dimensions of the machine. For instance, calculations indicated that by cutting the number of armature slots to half the number of armature coils or commutator bars, there would be an appreciable saving in slot space with a corresponding gain in iron section in the armature teeth which was one of the limiting conditions in the machine. However, this involved the use of two coils

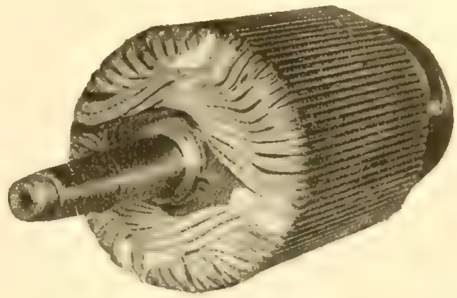


FIG. 11—ARMATURE OF WESTINGHOUSE NO. 12 MOTOR

side by side per slot and, with a four-pole machine it meant an unsymmetrical armature winding, for, with the two-circuit winding on a four-pole machine, an odd number of armature coils was necessary. This meant an idle coil, or idle coil space, on the armature. This was considered as detrimental in theory, but, on the other hand, it was believed that the wider armature slots with their lower self-induction, together with the much shorter armature core resulting from this construction, might compensate for some dissymmetry in the winding. This was only a theory, but it was thought worth while trying out. According to the calculations, with this construction together with higher speed due to increased gear ratio, the old No. 3 motor armature (keeping the same diameter) could be shortened about 40 percent and the field could be modified in proportion. This meant a very considerable reduction in size and weight and was well worth going after. A trial machine was built and tested and, instead of being materially poorer in commutation, it developed that the gain due to the wider slots and shorter core, more than offset any harmful effects of the unsymmetrical winding, so that the resultant machine was a somewhat better commutating, cooler, more efficient and much lighter machine than the No. 3. This was a somewhat startling result, but the tests showed conclusively that it was correct. It was then arranged to bring out a new Westinghouse motor to take the place of the No. 3. It was decided to go as far as possible in reducing the dimensions and weight of this machine and, therefore, the supporting or surrounding frame of the No. 3 motor was abandoned and extensions from the yoke of the motor itself, forming the end housings, were designed to carry the armature bearings. In this way a further reduction in weight resulted.

THE WESTINGHOUSE NO. 12 MOTOR

This new motor was known as the Westinghouse No. 12. In this motor the lower half of the field was enclosed by means of the end housings. The armature winding was of the formed-coil type, like the No. 3, arranged in two layers and with the end windings hammered down.

Very shortly after this motor was put out an improved form, known as the No. 12-A was brought out. This was quite similar in general to the No. 12. The principal improvement in the No. 12-A was in the armature construction. The armature core was ventilated, to secure increased continuous capacity and the armature winding was of the modern type with all coils of the same size and shape, and arranged symmetrically. The armature core of this machine was quite highly saturated at heavy load and this was found to materially improve the commutation. This No. 12-A motor was found to be quite superior to any preceding motors in its general characteristics, especially in its continuous capacity.

In its field construction it resembled the old No. 3, in the fact that it had cast iron yoke and poles and the field poles were cast integral with the yoke and were straight-sided so that the field coils could be slipped on directly over the pole tips. There was one feature in these motors and their variations which materially affected their operation, but which was not fully appreciated at the time they had been designed, namely, the effect of the cast-iron poles in improving the commutation. The pole tips of these motors, as a rule, were somewhat smaller in cross-section than the pole bodies or cores and, therefore, there was quite high saturation in the pole tips, particularly at heavy load. This high saturation had very much the effect of the "cut-away" pole corners, used later on laminated pole machines.

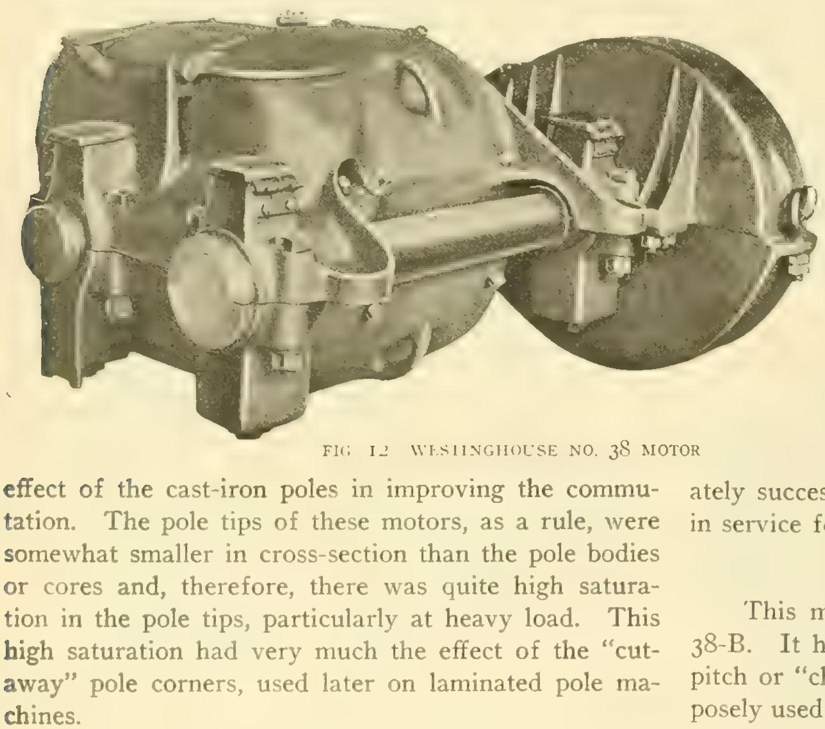


FIG. 12 WESTINGHOUSE NO. 38 MOTOR

THE WESTINGHOUSE NO. 38 MOTOR

Recognizing that in the No. 12-A motor the general type of construction had been carried as far as possible, due to the limitations in the cast-iron field structure, it was decided to attempt a different field construction, in which the limitations in design could be pushed up very considerably. This was embodied in the Westinghouse No. 38 motor. This motor, in general type, was similar to the No. 12-A, except that in the first motor built, the field was made of solid cast steel, both poles and yoke, with the poles cast integral with the yoke. This construction allowed very materially higher field fluxes than in the former motors, so much so that again the armature teeth became the limit in saturation. Therefore, in the armature three coils per slot were used instead of two, thus gaining in armature tooth section. This, the writer believes, was the first use of the three-coil-per-slot arrangement in railway motors. This first No. 38 solid steel pole motor showed unduly high losses due to the solid-pole construction. Immediately it was changed to laminated pole construction with the poles cast integral with the yoke. This apparently was the first use of laminated poles with steel yokes, in street railway motors.

This No. 38 motor represented, with minor differences, the present type of railway motor. One principal difference was in the cast-in laminated poles, instead of the present practice of bolted-in laminated poles. It had ventilated armature windings and relatively high saturation in the armature core to help commutation at heavy loads. Also with the three-coil-per-slot arrangement, with four poles, a more symmetrical armature winding was possible than in the two-coil-per-slot No. 12-A motor, there being no idle coils. In the former motors the bearings were lubricated with grease, as was the common practice in all motors at that time. However, when heavier and more difficult service was encountered, as was the case with the No. 38, which was of higher capacity than most of the former motors, it was found that the grease method was not very effective. This resulted in a modification which provided a felt wick and an oil well under both the armature and axle bearings, so that the motor was adapted for use either with grease or oil. This was on the No. 38-B, which was a modification of the No. 38. Like all compromises which attempt to adopt all the good features of all methods, it was only moderately successful, although it served to keep the motors in service for many years.

WESTINGHOUSE NO. 49 MOTOR

This motor had much the same lines as the No. 38-B. It had laminated poles cast in. The fractional pitch or "chorded" type of armature winding was purposely used in this motor to improve commutation, careful shop tests being made with an approximately full pitch and with various chorded windings to find what would give the best result. It was found that a "throw" of the armature coil, one and one-quarter slots less than full pitch, gave materially better commutation than any other combination. Chorded windings had been used on other types of machinery, to a limited extent, before this, but it is believed that this was the first time that it was used on a railway motor purely for the purpose of improving commutation.

THE G. E. NO. 800 MOTOR

This was a new motor gotten out by the General Electric Company to replace the W. P. It was a four-pole machine with two salient and two consequent poles.

This was a more symmetrical type of machine than the W. P., but yet was not a purely symmetrical machine, such as the Westinghouse motors from No. 3 on, and the later types of G. E. motors. Its designation of No. 800, was a new method of rating, to indicate its tractive effort instead of its horse-power. Its nominal rating was about 27 hp. This tractive effort method of rating was carried into several other sizes such as the G. E. 1200 and G. E. 1000.

This G. E. No. 800 motor was a very considerable improvement over the W. P., but possessed certain fundamental defects. For instance, the consequent pole arrangement meant very considerable magnetic fluxes through the shaft and bearings with consequent tendency for unipolar action in the bearings, the bearing shells and surface forming the collecting brushes. Therefore, there was a tendency for current in such bearings, as in all consequent-pole machines. It may be assumed that this defect was encountered, for in some of these motors very deep bronze shells were used, apparently for the purpose of introducing so large a gap in the shaft magnetic path that the flux through the bearings would be minimized to a non-injurious point. Moreover as in consequent pole machines in general, the commutating zones were not truly symmetrical and thus commutation troubles were, to a certain extent, existent.

A similar motor to the No. 800 was the No. 1200. Both of these motors persisted for several years, but were later dropped in favor of the radial pole type with salient poles of which the G. E. 1000 was an example.

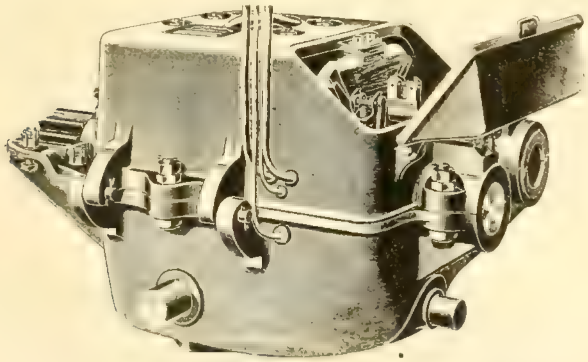


FIG. 13—G. E. 800 MOTOR WITH COMMUTATOR LID OPEN

From this point on the general design of the direct-current railway motors of all manufacturers has been practically along the same lines. In other words, a definite type has become universal. The fundamental features of this universal type may be classified as follows:—

1—Outside cylindrical or approximately cylindrical yoke.
2—Extension of the yoke to form protecting end housings and to carry the bearings.
3—Radial field poles, usually four in number.
4—Laminated field poles.
5—Bolted-in field poles.
6—Field coils without bobbin shells. (Mummified coils)
7—Drum wound armature.
8—Slotted armature core.
9—Two-Circuit or series direct-current winding.
10—Two or more armature coils per slot.
11—Machine wound armature coils, insulated before placing on the core.
12—Relatively thin mica between commutator bars.

It is of interest to note how many of these characteristics appeared in the very early motors. For instance, *1, 3, 6, 7, 8, 9, 11* and *12* all appeared in the original experimental Westinghouse single-reduction motor described, which later was developed into the No. 3. Item No. *2* appeared in the Westinghouse No. 12 and in the Thomson-Houston "W.P." motor.

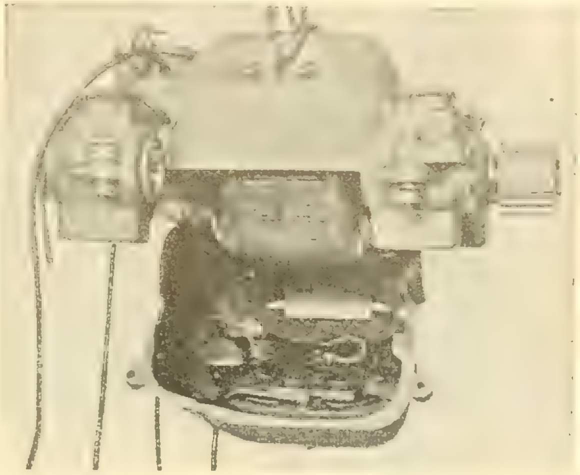


FIG. 14—G. E. 1000 MOTOR, OPEN

Item *4* first appeared in the Westinghouse No. 38 motor. Item *5* appeared in one of the earliest radial-pole G. E. motors and also in the Westinghouse Nos. 56, 68 and 69. Item *10* appeared first in the Westinghouse No. 12 motor.

Thus it is obvious that the Westinghouse No. 3 motor, in its first experimental form (back in 1890), contained nearly all the fundamental features of the present universal type. The end housings carrying the bearings and the laminated bolted-in poles, constitute the two principal additional developments. Moreover, the experimental No. 3 motor did partially contain the element of enclosing end housings. Thus it may safely be stated that the No. 3 motor practically fixed the type of the modern railway motor.

It may also be mentioned that there was much argument over the various types of armature windings used by different manufacturers. In connection with the machines-wound coil, as used on the No. 3 motor, many weird claims were made for it. In one case within the writer's knowledge, an over-enthusiastic representative of the company, with practically no knowledge of the matter, assured a customer (and he was doubtless sincere in his assurance) that spare coils could be carried along with the car and in case of a burn-out, the trap-door could be lifted and new armature coils dropped in place. In this case, fortunately, the customer actually knew both what could and could not be done and he had many a good laugh afterwards while telling the incident.

LATER MOTOR DEVELOPMENTS

Following the Westinghouse No. 49 and the G. E. No. 1000, the developments of the two companies might

be said to be so nearly along the same general lines that the differences were largely indetails, although some of the improvements in details were of great importance. A few of the improvements in the Westinghouse later motors might be mentioned. The General Electric Company had already adopted bolted-in poles, following the Westinghouse No. 38 motor with cast-in poles. The Westinghouse followed in its No. 56 and No. 68 motors

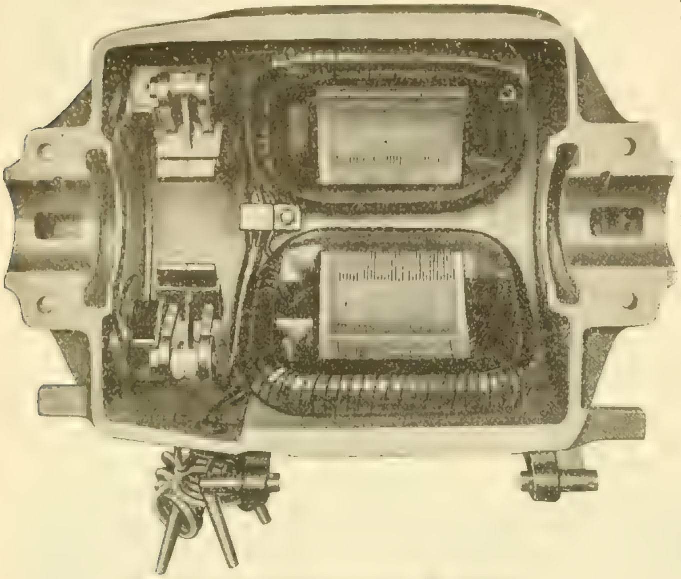


FIG. 15 WESTINGHOUSE NO. 68 MOTOR

with bolted-in poles. Both of these motors had ventilated armature windings and curved field coils, this latter practice being derived from the Walker and Lorain motors, both of which companies had been taken over by the Westinghouse. In the No. 68 motor the alternate corners of the pole tip laminations were cut away, in order to give a higher degree of saturation with heavy load and thus lessen the field distortion and reduce loss in the pole face. This had been common practice for some time in the railway generators. Various detail improvements were also incorporated, notably, brush holders with adjustable spring tension.

THE WESTINGHOUSE NO. 101 MOTOR

A most important step in the development of the street railway motor came in 1904 in the Westinghouse No. 101 motor. In this motor it was planned to incorporate all the requirements of service as indicated up to that time, together with all the good results found in previous motors. The No. 101-B motor, which was a modification of the original No. 101, has had a most enviable reputation. It contained a number of most desirable features, such as field coils, wound in a straight mould, of copper strap insulated with asbestos paper between turns; a symmetrical armature winding with three coils side by side per slot and no idle coils, armature coils banded solidly to coil supports, and completely enclosed; armature core and commutator built up on a spider, thus permitting the shaft to be replaced without interfering with the armature winding or core; brushholders insulated in the same way as more modern motors, with micarta tubes protected by cartridge shells, and clamped firmly in position, allowing for radial adjustment.

Probably the most noteworthy improvement in the No. 101-B motor was in the armature bearings and lubrication. The journals were made larger, the shafts of a higher grade of material and the old system of combined oil and grease was discarded and oil-soaked woolen waste was substituted. This motor had the armature bearings carried in housings which were bolted to the top half of the field and clamped between the two halves of the field. The housings had large reservoirs for the oil and waste and allowed for seperate gaging of the oil. This motor made a phenomenal record in respect to armature lubrication. Where former motors were overhauled each two or three months, in order to change the bearings, with the No. 101-B it was unnecessary to change bearings until they had been operated several years.

The above improvements were not added without a substantial increase in weight, which, however, was considered well worth while. This motor had a tremendous sale and there are still operating companies who prefer the No. 101-B to any of the more modern motors which have been developed. Other sizes corresponding to the No. 101-B were the No. 92 and No. 93-A.

COMMUTATING POLES IN RAILWAY MOTORS

The next great improvement in railway motors came in 1907 and 1908 in the use of commutating poles. In stationary motor practice, a number of electrical manufacturing companies had used commutating poles for motor work, especially for variable speed service over wide ranges. It was but a direct step from this to the use of commutating poles in railway motors. However, the General Electric Company was the first to put such motors on the market, to be followed soon after by the Westinghouse Company in their No. 300 line of motors, Nos. 305, 306 and 307 being motors

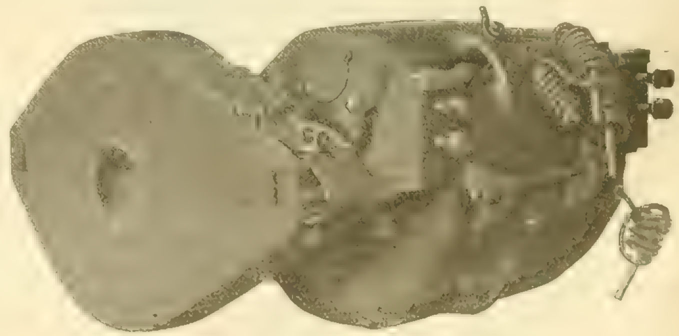


FIG. 16 WESTINGHOUSE NO. 101-B MOTOR

which corresponded to non-comutating motors immediately preceding them. These motors had all the mechanical characteristics and general features of design of their predecessors, with the addition of the commutating poles. Since that time commutating poles in railway motors have been so thoroughly established that no new railway motors would be considered without them.

LIGHT-WEIGHT MOTORS

Somewhat later than this an agitation was started against excessive weight in cars, trucks and electrical equipments. This agitation bore fruit, and a weight cutting campaign began which has resulted in the adoption of extremely light weight cars, trucks and motors. The question of car and truck design may not be discussed here, although it looks now as if the weight-cutting campaign has gone past the best limit. However, a large part of the reduction in the weight of motors has been entirely logical and is largely the result of careful design and improvements in ventilation. Motors are now built with large fans, mounted on the pinion end of the armature shaft, which pull air through the armature core and over the surface of the armature and between the field windings, which has made an increase of probably 50 percent in the continuous rating of the motors. In addition to this, the armature speed has been very considerably increased and the gears have, in many cases, been changed from 3-pitch, to 3½, 4 and even 4½.

Open ventilation of the motors has been a natural consequence of the great improvement in insulation made in the last few years. The early motors were made open to the weather but this had to be abandoned because of the large amount of insulation trouble. After a good many years with the enclosed motor, it gradually became the practice to open the motor up somewhat for better ventilation, and finally fans were installed to create a circulation of air, so that now the continuous rating of railway motors is higher per pound than ever before.

Essentials of Transformer Practice—XVI

Connections for Voltage Transformations

E. G. REED

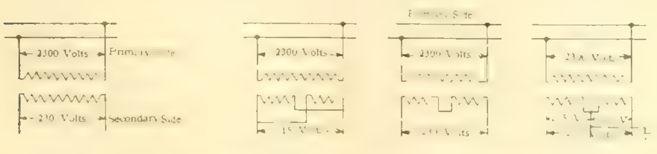
The following are some of the most important transformer connections for voltage transformations:—

1—Single-phase.
2—Three-phase by the various combinations of the star and delta.
3—Three-phase open delta.
4—Three-phase T.
5—Interconnected star.

This discussion does not go into detail regarding the vector relations of the voltages and currents, nor the k.v.a. of transformer parts required by the different arrangements, but merely shows the connections required to give the transformations.

SINGLE-PHASE CONNECTIONS

The simplest transformer arrangement is that shown in Fig. 1, since both the high and low-voltage



FIGS. 1 AND 2—THE COMMON METHODS OF CONNECTING LOW VOLTAGE, SINGLE-PHASE TRANSFORMER SECONDARIES

Fig. 1—The low voltage winding consists of one part.
Fig. 2—The low voltage winding is made in two parts.

windings are made up of one part without taps. The winding may be divided into parts and these parts connected for the different operating conditions. For example, most distributing transformers are made with two low-voltage coils, which may be connected as shown in Fig. 2, for parallel, series and three-wire operation. The series-parallel connection permits operation at full output at two voltages, one of which is double the other. The three-wire connection is extensively used, as it permits simultaneous feeding a combined lighting and power load. In this case the motors are connected to the two outside wires, and the lights between the outside wires and the neutral. The neutral of the three-wire connection gives a convenient point for grounding, when it is desired to connect the secondary of the transformer to the ground.

Taps are usually provided on transformer windings of the higher voltage classes, the main purpose of the taps being to obtain a given secondary voltage, when the transformer is used at points where the primary voltage is low, due to line drop or other reasons. The taps may be located on the transformer winding by either of the methods shown in Figs. 3 and 4. The one shown in Fig. 4 is used for the higher voltage transformers, where the insulation is increased on the end turns. With the connections shown in Fig. 4, this additional insulation need extend back but a short distance,

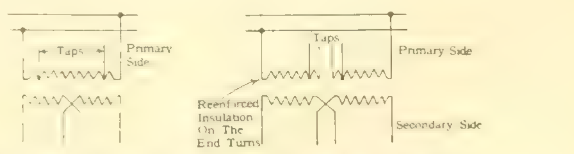


FIG. 3—TAPS ON THE LINE ENDS OF THE WINDING

FIG. 4—TAPS AT THE MIDDLE OF THE WINDING

while if the taps are on the line ends of the winding, the insulation must extend beyond the taps.

THREE-PHASE DELTA AND STAR CONNECTIONS

With the delta-delta connection, the windings are connected to the mains as shown in Fig. 5. The line voltage is equal to the individual transformer voltages, and is commonly denoted as the delta voltage to distinguish it from the voltage of the group connected in star. Similarly, the line current must be distinguished from the current flowing in the windings of the transformers. When speaking of the voltage and current of a three-phase system, the delta voltage and star current are understood.

Where 2300 to 230 volt transformers are connected delta-delta for a three-phase transformation, one of the

units is sometimes made larger than the other two, and the middle point of the low voltage winding is connected as shown in Fig. 5, giving a 230-115 volt single-phase three-wire lighting circuit. If one transformer, or one phase of a three-phase transformer is disabled, the other two may be used in open delta.

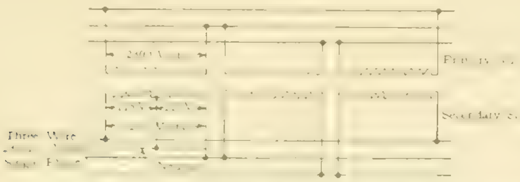


FIG. 5—DELTA-DELTA CONNECTED TRANSFORMERS FOR THREE-PHASE TRANSFORMATION

Showing a three-wire, single-phase secondary circuit on one transformer.

The delta-star connection shown in Fig. 6 is used to a considerable extent, since a fourth wire may be led from the neutral point of the low-voltage windings, thus giving a convenient and economical distributing system. Single-phase service is obtained by connecting between any line and the neutral, while for three-phase work the line wires are used, the voltage being $\sqrt{3}$ times the single phase voltage.

With a star-delta connection a neutral point is made available in case it is desired to ground the primary side of the transformer, or use the four-wire system. The four-wire system is mostly used for a combination of motor and lighting loads, the lighting service being operated from the 2300 volt phase voltage and the power service from the 4000 volt line voltage, as shown in Fig. 7. Transformers are sometimes designed so as to be suitable for either delta-delta or delta-star connection, in order to permit an increase in the capacity of a transmission line by raising the line voltage, which can be accomplished by changing the connections from delta to star on the high-voltage side. Such transformers are necessarily more expensive than they would be if designed for straight delta-delta, and used at the lower voltage only, because they must be insulated to withstand the higher line voltage. With the star-delta connection of three single-phase transformers, one unit may be cut out, and emergency service be maintained as shown in Fig. 8. The capacity

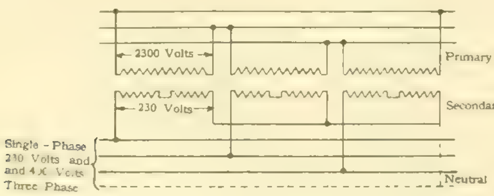


FIG. 6—DELTA-STAR CONNECTED TRANSFORMERS

Giving a four-wire, three-phase secondary circuit.

of the group is in this case reduced to 58 percent of its original value. The neutral connection on the high-voltage side should preferably be made through a wire, but can be made by solidly grounding the neutral, provided the neutral of the source of supply is also grounded.

The star-star connection of three single-phase transformers, or of a three-phase unit as shown in Fig. 9 is not to be recommended unless their neutrals are grounded.

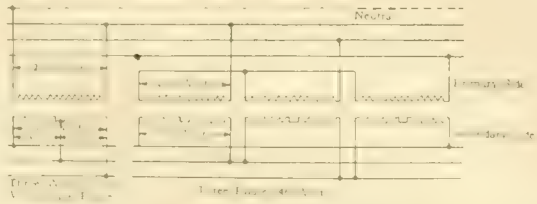


FIG. 7—STAR-DELTA CONNECTED TRANSFORMERS FROM A FOUR-WIRE PRIMARY CIRCUIT

Showing also the connections of a single-phase, three-wire transformer from the same primary.

OPEN DELTA CONNECTION

When three single-phase units or a three-phase shell-type transformer is used, it is possible to maintain operation if one of the single-phase transformers, or one winding of the three-phase unit, is damaged. This arrangement is shown in Fig. 10 and is known as the open delta or V-connection. With the three-phase core type design, the damaged phase cannot be isolated,

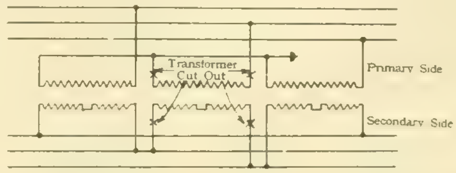


FIG. 8—EMERGENCY CONNECTION FOR THREE-PHASE TRANSFORMATION

When one transformer of a star-delta bank burns out and the neutral of the power source is grounded.

due to the interlinked magnetic circuits, and the open delta connection cannot be secured. With an open delta connected three-phase shell type transformer, the damaged phase should be short-circuited to prevent stray fluxes from the other phase from inducing voltages in the damaged windings.

T TO T CONNECTION

As with the open delta arrangement, the T to T connection requires only two single-phase transformers, as shown in Fig. 11. One of the units is called the main

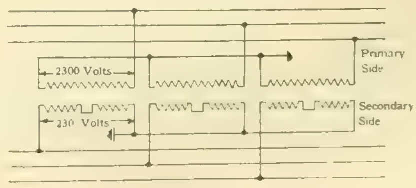


FIG. 9—STAR-STAR CONNECTED TRANSFORMERS

With the neutrals of both primary and secondary circuits grounded.

transformer and is provided with a 50 percent voltage tap, to which the teaser transformer is connected. The teaser unit may be designed for 86.6 of the line or main transformer voltage, but generally is made identical with the main transformer and operated at a reduced voltage. In this way it is possible to operate two iden-

tical transformers connected T to T, as well as open delta. Although interconnection is not required between halves of the main winding, yet each half of the primary winding must be properly wound with respect to the corresponding half of the secondary winding. Two ordinary transformers may also be used with the T to T connection, provided a 50 percent tap is available. It is also slightly more economical to operate with the T to T connection than with the V connection,

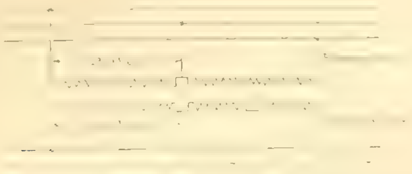


FIG. 10—OPEN DELTA CONNECTED TRANSFORMER

when one transformer has burned out. The T to T connection can be used for operating a synchronous converter, the transformer neutral being brought out for the three-wire direct-current service. The neutral is brought out from a point at one-third the height of the teaser winding, and the ampere turns of the direct current will neutralize each other.

INTERCONNECTED STAR CONNECTION

Synchronous converters are frequently installed when a three-wire direct-current circuit is required and the T to T connection is not suitable. The three-wire arrangement is obtained by connecting the neural wire to the neutral point of the low-voltage winding of the transformers. In such cases the connections should be arranged so that the direct current in each transformer divides into two branches of equal ampere turns. This is to prevent a unidirectional magnetic flux in the transformer which when superimposed on the normal magnetic cycle, would tend to raise the magnetic induction beyond saturation. This in turn would tend to cause excessive exciting current and heating, except in cases where the unbalanced current is comparatively small. Such a condition is shown in Fig. 12, which represents a delta-star connected step-down transformer with the

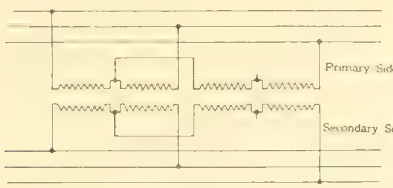


FIG. 11—T-T CONNECTED TRANSFORMERS

neutral brought out. In this case each transformer low-voltage winding receives one-third of the neutral current; and if this current is not small as compared with the exciting current of the transformer, it will cause an increase in the magnetic density. The interconnected star arrangement, as shown in Fig. 13, eliminates the flux distortion due to the unbalanced direct current in the neutral. Two separate interconnected windings are used for each leg of the star. The unbalanced neutral current flowing in this system may be compared in its action to the effect of a magnetizing current in a transformer. The effect of the main transformer currents in the high and low-voltage windings is balanced with regard to the flux in the magnetic circuit, which depends upon the magnetizing current. When a direct current is passed through the transformer,

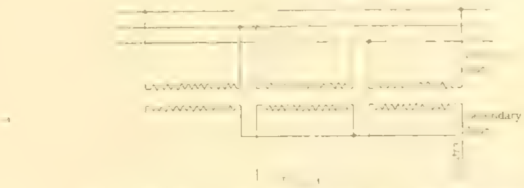


FIG. 12—DELTA-STAR CONNECTED TRANSFORMERS
For three-phase transformation to operate synchronous converters.

unless the fluxes produced by it neutralize one another, its effect on the transformer iron varies as the magnetizing current. For example assume a transformer having a normal current capacity of 100 amperes and approximately six amperes magnetizing current, and assume that three such transformers are used with star-connected, low-voltage windings for operating a synchronous converter connected to a three-wire system. Allowing 25 percent unbalancing, the current will divide equally among the three phases, giving 8.3 amperes per phase, which is more than the normal magnetizing current. The loss due to this current, however, is inappreciable, but the increased iron loss may be considerable. If a distributed winding is used, the direct current flows in opposite directions around the two halves of each winding, thus neutralizing the flux distortion.

Whether the simple star or the interconnected star connection is to be used in a particular case, is a question of balancing the increased iron loss of the straight star connection against the increased copper loss, and the greater cost of the interconnected star arrangement. The straight star connection is much simpler, and it would be permissible to use it for transformers of small capacities where the direct current in the neutral is not

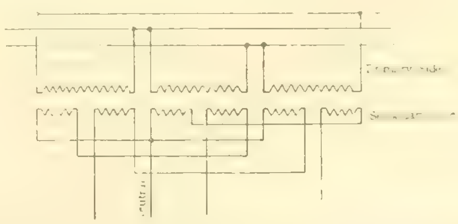


FIG. 13—DELTA TO INTERCONNECTED STAR CONNECTION
For three-phase transformation to operate synchronous converters.

more than 30 percent (10 percent per transformer) of the rated transformer current.

With three-phase core-type transformers, it is not necessary to use the interconnected star connection, as in such transformers the direct-current flows along the magnetic circuit in the same direction in all three legs. Since the direct flux must find its return path through the air and the case outside of the magnetic circuit, its effects are practically negligible.

Design and Selection of Oil Circuit Breakers

J. N. Mahoney

FOR INTERRUPTING large amounts of alternating-current power and for controlling high-voltage alternating-current circuits there is nothing superior to oil circuit breakers. There are two fundamental reasons for this:—First, this type of circuit breaker terminates the alternating wave at its normal zero value, eliminating excessive surges in the connected circuits; second, this form of apparatus is compact, due to the use of oil insulation.

When an oil circuit breaker is opened under load, an arc is formed between the stationary and the moving contacts whose size depends upon the voltage, the amount of current and the rate of contact separation. The heat of the arc disintegrates some portion of the oil and contacts, forming gas whose displacement and resulting pressure depends on the amount of current flowing and on the duration of the arc. If this gas is immediately carried away from the contacts, and the contacts have been sufficiently separated, the arc will persist only until the next zero of the current wave.

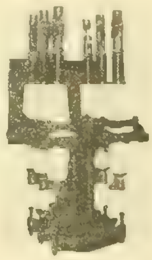


FIG. 1—600 AMPERE, 25 000 VOLT, THREE-POLE, OIL CIRCUIT BREAKER

Having 850 ampere breaking capacity at rated voltage. Weight, with tank and oil, approximately 500 pounds. Figs. 1 and 2 are reproduced to the same proportionate scale of linear dimensions.

The ability of the gas to rise away from the contacts depends upon the relative specific gravity of the gas and of the oil, and the clearance, head, volume and viscosity of the oil.

The relation of the horizontal section of the oil to the cross-sectional area of the contact and terminal arrangements will also determine the ease with which the gas will clear itself of the contacts. If there is a liberal clearance for oil around the contacts and if the oil movement is unimpeded, the pressure of the head of oil will force the gas out into the free oil space, and up to the expansion chamber, and clean cool oil will displace the gases.

The reason an oil circuit breaker in high voltage service quenches the arc is that the voltage and therefore the power through any given pole passes through zero and permits the arc to cease for a very short period of time. It is only when the products of combustion in the arc, or in other words the portion of oil and other volatilized materials are present in excessive quantity in the vicinity of the contacts that the arc fails to extinguish at zero or restarts after crossing zero. Under this condition, which is caused in some instances by attempting to break too large a current in too small a space, the re-establishment or presence of voltage in the circuit after crossing the current zero finds the vicinity of the contacts surrounded by "ionized" gases which are conducting when the voltage wave reaches a certain value, and cause the arc to persist, blowing the oil out and spreading to the sides of the tank if the receptacle is strong enough, or destroying the apparatus by the resulting gas pressure or explosion, if the tank or oil enclosing structure is mechanically inadequate.

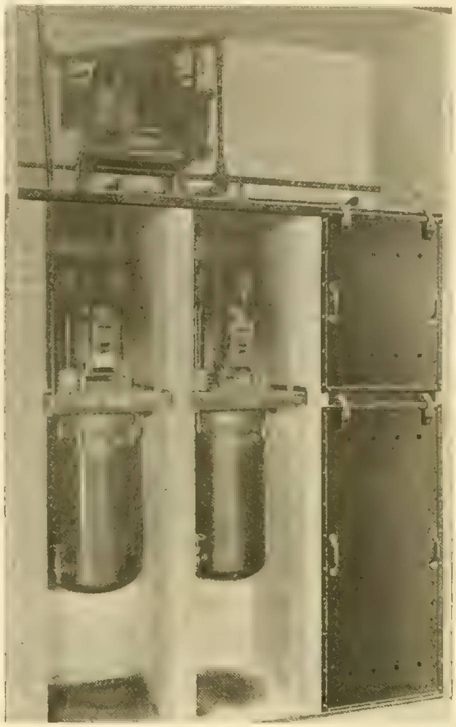


FIG. 2—600 AMPERE, 25 000 VOLT, THREE-POLE OIL CIRCUIT BREAKER

Having 11 500 amperes breaking capacity at rated voltage. Weight, with tanks, oil and operating mechanism, but without supporting structure or barriers, approximately 3500 pounds.

In view of these considerations, it is obvious that a circuit breaker of high interrupting capacity (i. e. for connection directly to a large system) must be much larger and stronger than one having the same current and voltage ratings, but of lower required interrupting capacity. For example compare the circuit breaker in Fig. 1, which has a rated breaking capacity of 850 amperes at rated voltage with that in Fig. 2 which has the same current and voltage rating but has a breaking capacity of 11 500 amperes. The circuit breaker, Fig. 1, weighs about 500 pounds complete whereas that in Fig. 2 weighs approximately 3500 pounds in addition to the weight of the structure in which it is mounted. A comparison of the strength of details, volume of oil, head of oil, length of break, design and size of oil tanks,

power of operating mechanism, etc. will show that all of these are much greater in Fig. 2 than in Fig. 1.

The volume of the arc and the instantaneous pressure in a given tank design caused thereby, increase both with the current and voltage. This requires:—first, that the circuit breaker have stronger parts with increased rated interrupting capacity; and second, that the length and speed of break and insulation clearance be greater to compensate for the increased ionization caused by the greater volume of energy dissipated instantaneously within the tank structure. The design data and proportions of oil circuit breakers have been determined by test, practice and experience. It is however quite possible to get the break distance between contacts too long and any liberality in design should

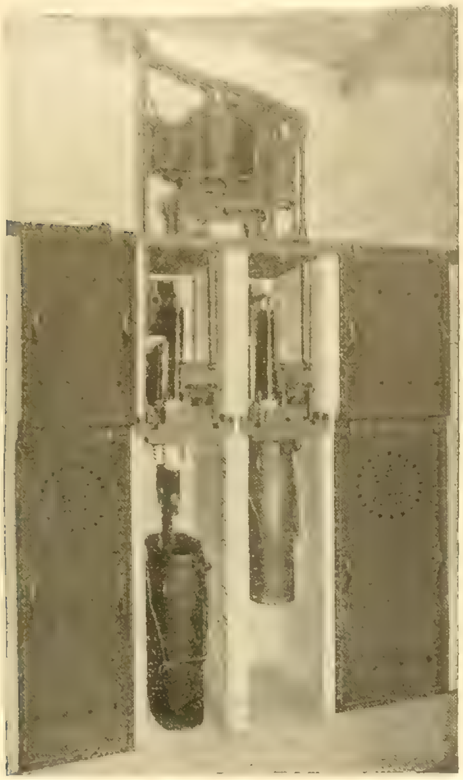


FIG. 3—300 AMPERE, 25 000 VOLT, FOUR-POLE, OIL CIRCUIT BREAKER

Having a breaking capacity rating of 1150 amperes. Shown in the open position with one oil tank lowered and two double doors of the cell structure removed.

preferably be in the direction of having a large head and volume of oil and in strengthening parts that are subject to pressure. The relative strength of loaded mechanical parts, maintenance of insulation and facilities for minimizing the volume and pressure of the arc gases are the principal controlling features finally determining the interrupting capacity at any given voltage. The contact details should have sufficient thermal capacity to withstand the maximum current on short-circuit as well as to carry normal current continuously. This feature is the determining one in circuit breakers of large required interrupting capacity but small required conducting capacity.

The current density in the contacts and other conducting features of the circuit breaker is determined by the form of contact used and the capacity of the circuit breaker. As is well known, the skin effect increases with the volume of current in any alternating-current conductor and hence the current density throughout the conducting structure as a rule should reduce as the circuit breaker increases in conducting capacity. The contact current density in wedge and finger type contacts, Fig. 4, approximates 100 amperes per square inch in the 200 ampere sizes and below and as low as 65 amperes per square inch in the 2000 ampere size. With laminated high pressure brush contacts, Fig. 5, the density will approximate 600 amperes per square inch in the 300 ampere size and as low as 300 amperes per square inch in the 4000 ampere size in 60 cycle service.

In general the following points should be kept in mind in making a comparison of oil circuit breaker designs:—

1—Rated capacity in volts and amperes, interrupting amperes and greatest momentary conducting amperes.
2—Total length of break and number of breaks per pole.
3—"Distance-time" curve of the contact movement.
4—Head of oil over upper position of contacts or arc.
5—Pressure that tank with complete supports and fastenings will withstand without permanent distortion.
6—Gallons of oil per tank and number of tanks.
7—Size of expansion chamber above oil per tank deducting for space occupied by insulator bushings, operating rod, etc.

RATING

The selection of an oil circuit-breaker for application to an electrical system requires a knowledge of the characteristics both of the circuit breaker and of the system or circuit. Circuit breakers are usually classified according to their rated voltage, current, frequency and interrupting capacity. Systems may be classified according to their normal operating voltage, current, frequency and current transients.

The rated voltage of a circuit breaker is the greatest normal voltage in r.m.s.* volts between any two wires of any circuit to which the circuit breaker should be connected. It is a function of its insulation strength and of the safety factor desired. The American Institute of Electrical Engineers has established standards for the insulation strength of oil circuit breakers** which require that they shall withstand a dielectric (clean and dry) test of 2.25 times rated pressure in volts, plus 2000 volts for 60 seconds.

The normal operating pressure of a system is the greatest pressure in r.m.s. volts ordinarily maintained between any two conductors.

The rated current of a circuit breaker is the greatest current in r.m.s. amperes which it will carry continuously at a specified frequency without any essential part having its temperature raised more than a specific

*R.m.s. is an abbreviation of the term "root-mean-square." It is the current or pressure read on an ammeter or voltmeter, and is sometimes called the effective value of the wave. It is defined as the square root of the mean of the squares of the instantaneous values of the current or pressure during one complete cycle. The r.m.s. value of a sinusoidal wave is equal to its maximum or crest value divided by the square root of two.

**These are contained in "Dielectric Strength Tests",—Sections 491, 492, 454, 486, 500 and 509 of the Standardization Rules of June 28th, 1916.

number of degrees above an ambient temperature or above a fixed temperature.*

The normal current in a circuit of an electrical system is the rated r.m.s. amperes for which that circuit is designed. The actual current may vary through wide limits from day to day and at different seasons of the year. The upper limit for continuous operation or the rated current is, however, fixed by the capacity of the conductors as determined by the maximum allowable temperature at which the conductors and their insulation may be operated. When circuit breakers are mounted in enclosed spaces, as in cell structures, special care should be taken to provide ventilation for the compartments.

Inasmuch as a circuit breaker reaches its final temperature quickly with steady current load, it is necessarily a maximum rated device. Thus, if the full-load current of a maximum rated machine is 2000 amperes, a 2000 ampere-rated circuit-breaker can be applied to handle the current of this machine. If the machine, however, has a 25 percent overload rating of an hour or more, a 2500 ampere circuit-breaker must be selected. On 25 cycle service, a circuit-breaker above 300 ampere rating will carry, continuously, considerably more than its 60 cycle rating.

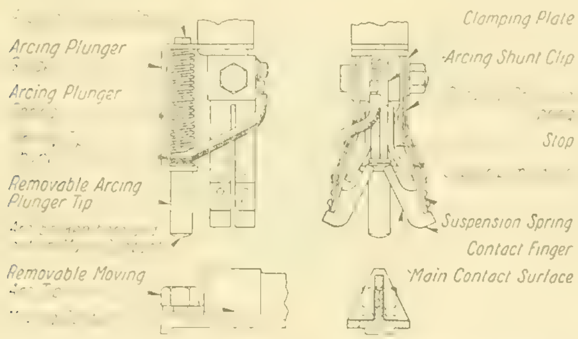


FIG. 4—DETAILS OF WEDGE AND FINGER TYPE CONTACTS

The interrupting capacity** of an oil circuit-breaker is the highest current in r.m.s. amperes which it will interrupt at any specified normal pressure, frequency and duty.

The usual interrupting rating adopted by the several manufacturers assumes that the circuit breaker will interrupt a circuit two times at a two-minute interval and then be in condition to be closed and carry its rated current until it is practicable to inspect it and make any necesary readjustments. This definition of interrupting capacity selects the most common condition of oil circuit breaker operation. In so doing, it places a definite limit upon the rating of a breaker. Circuit breakers may, however, be otherwise rated for different definitions of interrupting capacity or duty. If, for example the circuit breaker is required to perform but one successful interruption, it may be rated higher than it would if called upon to perform two successful interruptions at a two-minute interval. Also if it is required to perform ten successful interruptions at one-half minute intervals, it will be rated lower than if called upon to perform two successful interruptions at a two-minute interval.

The duty performed by a circuit breaker in interrupting the current at a given voltage is dependent upon the current volume and is a maximum for the largest current. Similarly, the duty at varying voltages for a given current is increasingly more difficult at high voltages. A given circuit breaker for any voltage—within its rating and under proper normal adjustment—has a certain maximum current interrupting ability.

EFFECT OF CIRCUIT CONSTANTS

The arrangement and constants of the connected electrical circuits have an influence on the duty to be performed by the oil circuit breaker. The power-factor and the stored electrostatic and magnetic energy of the system materially affect the interrupting capacity at a given r.m.s. current. During the current opening period, an arc is established and the current and voltage relations during this period are much more complicated than the simple phase angle relation covered by the statement of power-factor. Furthermore, the arc may be re-established under transient voltage conditions, introducing still further complications. These factors are of special importance when a circuit breaker of relatively small interrupting capacity is connected to a large system in such a way that it may afford the only outlet for the stored energy of the system. Such influences, while extremely difficult to take into account quantitatively, will not differ widely in average radial distributing systems. The problem of application after the service voltage has been fixed is to determine the maximum current that may be encountered and then the circuit breaker should be chosen with an interrupting ability equal to or greater than this maximum current.

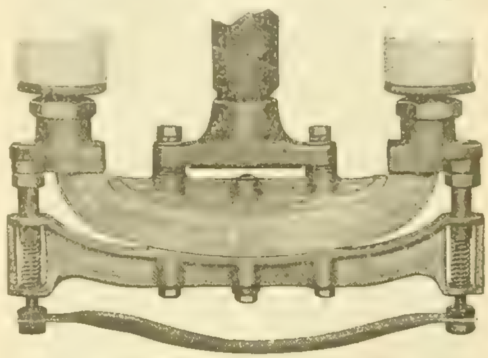


FIG 5—DETAILS OF LAMINATED BUTT CONTACTS

*The American Institute of Electrical Engineers heating standards for oil circuit breakers, in Section 754 of the 1917 supplement to Standardization Rules dated June 28th, 1917, limit the maximum permissible temperature rise of coils and insulating materials of oil circuit breakers to 50 degrees C. and the rise of other structural parts to 65 degrees C. based on an ambient temperature of 40 degrees C. They also limit the maximum temperature of oil and contacts in oil to 70 degrees. For an ambient temperature of 40 degrees this permits a temperature rise of 30 degrees for oil and contacts in oil. Where, however, the ambient temperature is less than 40 degrees, advantage may be taken of the condition to operate the parts at a higher temperature rise, if the maximum temperatures specified are not exceeded.

**This conforms with the standards listed under Section 753 of the Supplement of the A.I.E.E. Standardization Rules dated June 28th, 1917.

The current transient at any point in an electrical system is a variable depending on the resistance, inductance, electrostatic capacitance, mechanical capacity and current conditions of the circuit. It represents a readjustment of the stored electromagnetic and electrostatic energy in the system from an initial steady condition until a final steady condition is reached. It is manifested during every change in the steady condition of the circuit, although its effects on the circuit are usually inappreciable. Under certain conditions such as short-circuits, its effects, however, are of prime importance.

Short-circuiting a system at any point permits an abnormal current rush to occur immediately on that system. During the first complete cycle following short-circuit, the current usually rises to maximum value. If the alternator field exciting circuit is assumed to remain unchanged by automatic generator voltage regulators or similar devices, then during succeeding cycles, the current will rise in lesser and lesser peak wave values until a steady condition again exists on the system. The current wave during the transient period, as shown by oscillograms, may be symmetrical or unsymmetrical with respect to the line representing zero current, depending upon the point on the pressure wave at which the short-circuit occurred. The transient current is said to be symmetrical when the assumed line connecting points on the current wave midway between the peaks coincides with the line of zero current. Similarly, a transient current is said to be unsymmetrical when the assumed line connecting points on the current wave midway between the peaks does not coincide with the line of the zero current.*

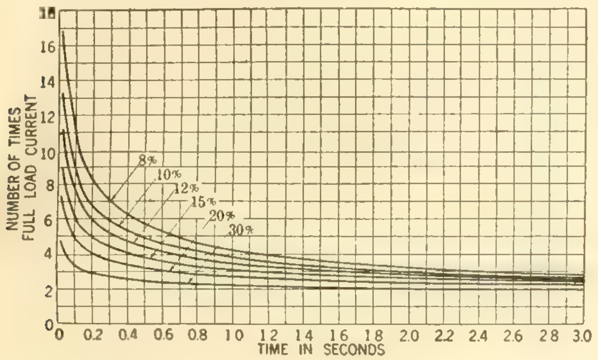
The value of the current at any instant, if referred to the line representing zero current, is a measure of the magnetic stresses produced on the conductors by the current. The magnitude of these stresses (which are proportional to the square of the current) is indicated by the breaking of insulators supporting busses, the displacing of windings of transformers and generators, the distortion of oil circuit breaker connections and the fusing of conductors in various parts of electrical systems.

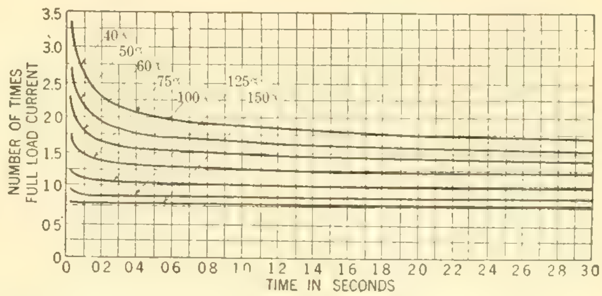
The maximum unsymmetrical value of a transient current in r.m.s. amperes during a short-circuit on an ordinary alternator is approximately equal to twice the generated pressure in volts immediately preceding the short-circuit divided by the impedance in ohms of the circuit between the point of power supply and the point of short-circuit. The maximum symmetrical value of the transient current is approximately equal to one-half the maximum unsymmetrical value.

The transient characteristics of an electrical system at a point remote from the source of power supply will be different from that of an alternator. Its amplitude and duration will depend upon the electrical constants of the system and the distance between the point of short-circuit and the source of power and the greater this distance the less the amplitude of the transient and the shorter its duration.

Automatic voltage regulators introduce system transients differing from those which occur in systems not so equipped. They tend to maintain the system pressure constant, but on account of the inherent time lag of the iron portions of the alternator and exciter armatures and fields, their effect is not felt immediately. The effect of automatic voltage regulators on system transients may be predicted for any known set of conditions and account taken of such effects in the application of oil circuit breakers. They effect the sustained short-circuit currents considerably and the initial short-circuit current but slightly.

The operating delay of oil circuit breaking mechanisms has an appreciable effect upon the current which they will be called upon to interrupt under transient conditions. The contacts of ordinary oil circuit breakers part in from 0.05 to 0.50 second after the tripping circuit is energized, depending on the operating mechanism and tripping means used.





FIGS. 6 AND 7—SHORT-CIRCUIT CHARACTERISTICS OF SYSTEMS HAVING 8 TO 150 PERCENT TOTAL REACTANCE, BASED ON THE TOTAL K.V.A. OF SYNCHRONOUS MACHINES CONNECTED TO THE SYSTEM

The curves represent root mean square short-circuit currents expressed in terms of the full-load current of the machines, an initial full load at 80 percent power-factor being assumed.

CIRCUIT BREAKER SELECTION

The new rating of oil circuit breakers in r.m.s. current interrupted* at normal operating pressure simplifies the selection of a proper unit for a given known

*See articles on "Generator Short-Circuit Current Waves" by F. D. Newbury in the JOURNAL for April '14, p. 196; and "Short-Circuit Current of Alternators" by F. T. Hague in the JOURNAL for May '16, p. 212.

*See article by the author on "Breaking Capacity Rating of Oil Circuit Breakers" in the JOURNAL for Nov. '13, p. 1103.

service condition. For average radial distributing systems, a determination of the r.m.s. current that will flow at the instant the contacts part, irrespective of power-factor or circuit conditions, will enable one to select the proper circuit breaker.

Determination of Short-Circuit Current—In order to determine the r.m.s. current that the circuit breaker will be required to open, an analysis of short-circuit phenomena is necessary. Short-circuiting a system at any point permits an abnormal current to flow immediately in that system. The amount and persistency of this current rush depend upon the characteristics of the synchronous apparatus connected to the system at the time and upon the impedance in circuit between the synchronous apparatus and the point of short-circuit. The value of r.m.s. current which the circuit breaker will be called upon to interrupt will depend upon the length of time that elapses between the start of the short-circuit and the parting of the contacts, as will be

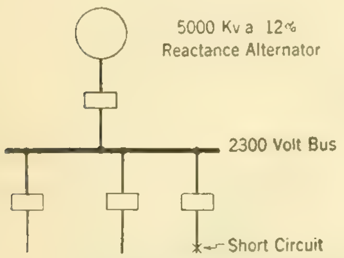


FIG. 8—CALCULATIONS OF SHORT CIRCUIT CURRENT

Alternator rating 5000 k.v.a., 2300 volts, three phase, 1250 amperes. The circuit breaker contacts part in 0.25 seconds after the start of the short-circuit. From Fig. 6, under 12 percent reactance, it is found that at 0.25 seconds the current equals 5.54 times normal, therefore the short-circuit current equals 5.54 · 1250 amperes = 6950 amperes.

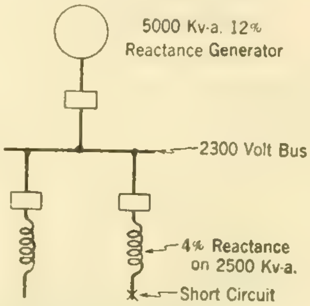


FIG. 9—CALCULATION OF SHORT CIRCUIT CURRENT

Alternator rating 5000 k.v.a., 2300 volts, three phase, 1250 amperes. Feeder rating, 2500 k.v.a. Feeder reactance, four percent, based on 2500 k.v.a. The circuit breaker contacts part in 0.25 seconds after the start of the short-circuit. The alternator reactance based on 5000 k.v.a., equals 12 percent. The feeder reactance based on 5000 k.v.a., (5000/2500 × 4) equals 8 percent. Hence the total reactance based on 5000 k.v.a. equals 20 percent. From the curves under 20 percent reactance, it is found that at 0.25 seconds the current will be 3.82 times normal. Therefore the short-circuit current equals 3.82 × 1250 amperes = 4780 amperes.

seen from the following analysis of short-circuits. The greatest transient disturbance of the system which can occur at the point of application of the circuit breaker, when the system is short-circuited, governs the selection of a suitable breaker.

The correct application of an oil circuit breaker to an electrical system or circuit requires that certain characteristics of the circuit breaker and of the system or circuit be known or assumed. The oil circuit breaker characteristics are:—

1—Rated voltage.

2—Rated current.

3—Greatest momentary current conducting capacity.

4—Current-interrupting capacity.

5—Time interval between the instant of short-circuit or overload and the instant the circuit breaker contacts part.

The system or circuit characteristics are:—

1—Normal voltage.

2—Normal current carried by the circuit in which the circuit breaker is connected.

3—Normal frequency.

4—Normal k.v.a. capacity of synchronous apparatus, transformers, reactors and lines.

5—Abnormal current characteristics during short-circuit or overload.

The circuit-breaker characteristics can usually be determined by test, or are given by the manufacturer.

The r.m.s. current at any point of a system under short-circuit conditions is affected by the following factors:

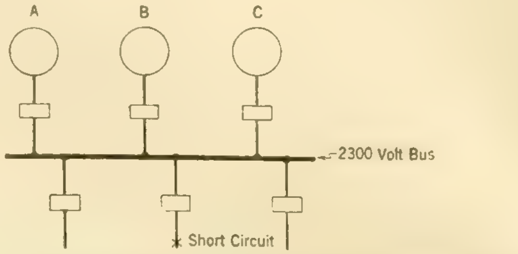


FIG. 10 CALCULATION OF SHORT-CIRCUIT CURRENT

Alternator A rated 2000 k.v.a., 2300 volt, three-phase, reactance = 8 percent.

Alternator B rated 5000 k.v.a., 2300 volt, three-phase, reactance = 12 percent.

Alternator C rated 8000 k.v.a., 2300 volt, three-phase, reactance = 16 percent.

Total alternator k.v.a., 15 000.

Normal current based on 15 000 k.v.a., 2300 volts = 3760 amperes.

Circuit breaker contacts part in 0.4 seconds after the start of the short- circuit.

Alternator A reactance based on 15 000 k.v.a., $\left(\frac{15\,000}{2000} \times 8\right) =$ 60 percent.

Alternator B reactance based on 15 000 k.v.a., $\left(\frac{15\,000}{5000} \times 12\right) =$ 36 percent.

Alternator C reactance based on 15 000 k.v.a., $\left(\frac{15\,000}{8000} \times 16\right) =$ 30 percent.

Total reactance at bus $= \frac{1}{1/60 + 1/36 + 1/30} = \frac{1}{14/180} = \frac{1}{0.0775} = 12.85$ percent.

From Fig. 6, interpolating between 12 and 15 percent reactance, it is found that at 0.4 seconds the current will be 4.5 times normal; therefore, the short-circuit current equals 4.5 × 3760 amperes = 17 000 amperes.

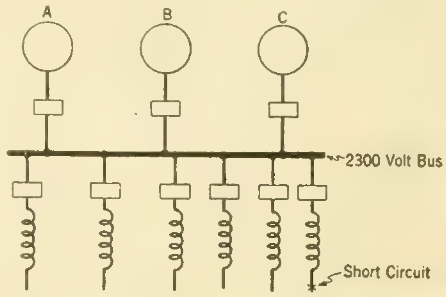


FIG. 11 CALCULATION OF SHORT-CIRCUIT CURRENT

Same as Fig. 10, except that power is distributed over 2500 k.v.a. feeders in which are installed current limiting reactors having a reactance of three percent based on 2500 k.v.a. The circuit breaker contacts part in 0.4 seconds after the start of the short-circuit.

Total alternator reactance based on 15000 k.v.a. = 12.85 percent.

Feeder reactance based on 15 000 k.v.a. $= \left(\frac{15\,000}{2500} \times 3\right) = 18$ percent.

Total reactance based on 15 000 k.v.a. = 30.85 percent.

From Fig. 6, using 30 percent reactance, it is found that at 0.4 seconds the current will be 2.6 times normal; therefore, the short-circuit current equals 2.6 × 3760 amperes = 9700 amperes.

1—The total k.v.a., reactance and transient characteristics of the synchronous machines connected to the system.

2—The number, reactance, resistance, capacitance and arrangement of all circuits over which power can be supplied to the point of short-circuit.

3—The k.v.a. capacity, arrangement, resistance, reactance and capacitance of all reactors and transformers through which power can be supplied to the point of short-circuit.

4—The contact resistance at the short-circuit.

5—The nature of the short-circuit, whether single-phase or polyphase.

6—The k.v.a. and power-factor of the load being carried at the time of short-circuit.
7—The point of the pressure wave at which the short-circuit was established.
8—The use of automatic voltage regulators.

The short-circuit transient for systems may be determined by test, by calculation or, less closely, by assumption. Obviously, the determination by test will be practicable in but few cases. The determination by calculation is feasible if only the important factors listed above are considered. Practical approximate selection, sufficiently accurate for many cases, can be made by using only reactance and an accepted group of time current decrement curves, such as those given in Figs. 6 and 7.* These curves are based on the transient characteristics for alternators of normal design

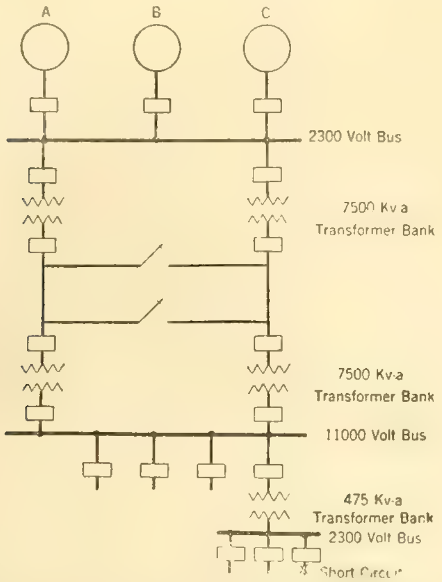


FIG. 12—CALCULATION OF SHORT-CIRCUIT CURRENT

Alternators same as for Fig. 10. The circuit breaker contacts part in 0.1 seconds, after the start of the short-circuit.
Two transformer banks each of 7500 k.v.a., whose reactance equals 6.25 per cent based on 7500 k.v.a. each.
Two lines, each 20 miles long of 0 copper, whose reactance equals 5.5 percent, based on 7500 k.v.a. each.
Total alternator reactance based on 15 000 k.v.a. = 12.85 percent.
Parallel reactance of step up transformers, based on 15 000 k.v.a. = 6.25 percent.
Parallel reactance of lines, based on 15 000 k.v.a. = 5.5 percent.
Parallel reactance of step down transformers based on 15 000 k.v.a. = 6.25 percent.
Total reactance = 30.85 percent.
From Fig. 6, using 30 percent reactance, it is found that at 0.1 seconds the current will be 3.4 times normal. The normal current based on 15 000 k.v.a., 11 000 volts, three-phase = 788 amperes; therefore, the short-circuit current equals 3.4 × 788 amperes = 2700 amperes.

which have been determined from oscillograph tests. They are further based on the assumption:—

That the effect of capacitance and resistance is neglected;
That the contact resistance as short circuit is zero;
That the alternator is carrying full load 80 percent power factor;
That the short circuit was established at the point of the pressure wave corresponding to maximum possible instantaneous current; and
That no automatic voltage regulators are used.

These curves differ from those that have been usually considered in the past for two reasons; first, r.m.s. values are used instead of peak values and, second, the effect of the increased flux existing under the load condition assumed has been taken into account.

*From a paper by Messrs. Hewlett, Mahoney and Burnham before the A.I.E.E. Feb. 15, 1918.

The shapes of the time current decrement curves have been arrived at by analysis of alternator tests including oscillograph studies of short-circuits occurring when the alternators were excited to full voltage and were carrying various loads at various power-factors. In the curves for total reactances up to and including 20 percent, the reactance is assumed to be wholly within the alternator and for higher values of reactance the alternators were taken at 20 percent and due allowance made by calculation for the effect of the external reactance. In the latter case, if alternators of other reactance had been supposed the results would have been somewhat different but the error is not large enough to be of practical importance. The final values of the current, i. e., the sustained short-circuit current, have been assumed in accordance with experience and tests and are based on the behavior of machines of normal

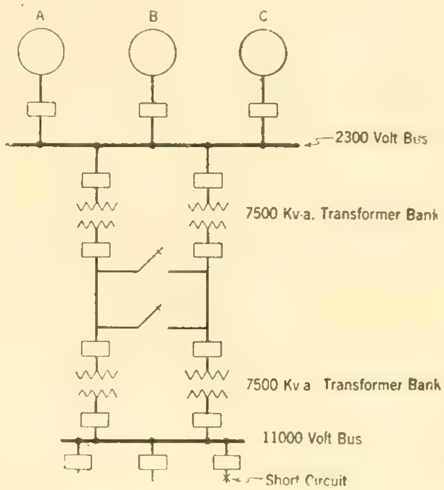


FIG. 13—CALCULATION OF SHORT-CIRCUIT CURRENT

Conditions same as for Fig. 12, except that a 475 k.v.a., 2300 volt feeder has been added to the low-voltage distribution, whose reactance is three percent based on 475 k.v.a. The circuit breaker contacts part in 0.4 seconds after the start of the short circuit.
Total reactance up to 11 000 volt bus based on 15 000 k.v.a. = 30.9 percent.
Feeder transformer reactance based on 15 000 k.v.a. $= \left(\frac{15000}{475} \times 3\right) = 94.5$ percent
Total reactance based on 15 000 k.v.a. = 125.4 percent.
From Fig. 7, using 125 percent reactance, it is found that at 0.4 seconds the current will be 0.87 times normal. The normal current based on 15 000 k.v.a., three-phase, 2300-volts = 3760 amperes, therefore the short-circuit current equals 0.87 × 3760 amperes = 3300 amperes.

design on polyphase short-circuit. The final values may be approximately 40 percent higher on single-phase short-circuits.

Several alternators with the same reactance and synchronous impedance will not necessarily have the same rate of r.m.s. current decay. This has been considered in constructing the characteristic curves and they may safely be taken as representing the greatest r.m.s. current that will be given by modern alternators of normal design on polyphase short-circuit. While the initial current will be approximately the same on single-phase short-circuit the rate of current decay is slower than on polyphase short-circuits.

The values given in the curves in Figs. 6 and 7 are for three-phase short-circuits on three-phase systems and also are high enough for single-phase short-circuits on ungrounded neutral three-phase systems and corresponding single-phase systems. For single-phase

short-circuits on solidly grounded neutral three-phase or single-phase systems, the initial current is slightly higher than given in the curves and the sustained short-circuit values are 100 to 150 percent higher than the curve values. However, where the neutral is grounded through a limiting resistance or only through one machine, the values on the curves are applicable.

Two-phase systems will have essentially the same characteristics as corresponding three-phase systems with the same qualifications as outlined above.

Where two-pole circuit breakers are used to open short-circuits between a line and the neutral, the leg current interrupting capacity of the breaker is that corresponding to 0.58 times the phase voltage.

Short-circuits in cables are not instantaneous in nature but develop gradually into dead short-circuits. In such cases a current sufficient to actuate the circuit breaker relay may pass, and develop into a dead short-circuit by the time the contacts open. Where full protection is required for such cases a circuit breaker good for the initial value of short-circuit current shown on the curves should be used.

These curves are applicable for selecting circuit breakers for systems as follows:—

1—Single machines without external reactance.
2—Single machines in combination with external reactance.
3—Multiple machines with no external reactance.
4—Multiple machines in combination with external reactance.

The percentage reactance in any line of a circuit is the reactance drop in that line at normal current, expressed as a percent of the voltage to the neutral of that circuit, which equals the voltage between wires divided by 1.73 for three-phase and the voltage between wires divided by 2 for single or two-phase systems.

In order to illustrate the use of the curves in Figs. 6 and 7 several typical examples are worked out in connection with Figs. 8 to 13 inclusive. With reactances of 125 percent or more, the portion of the total reactances in the generator becomes of relatively small importance. In Fig. 13 for instance, there is a total reactance of 125.4 percent. The alternators in this example have a reactance of 12.9 percent. If the reactance of the external circuit only is considered the total reactance is 125.4—12.9 = 112.5 percent. The short-circuit current on this basis would be 100 ÷ 112.5 × normal or 0.890 × 3760 = 3340 amperes. A comparison of this value with the 3270 amperes obtained by considering the alternator reactance shows an error of approximately two percent. If the total reactance is greater than about 125 to 150 percent, the error will be even less than two percent. Hence for values of external reactance in excess of the table values the alternator reactance may be omitted.

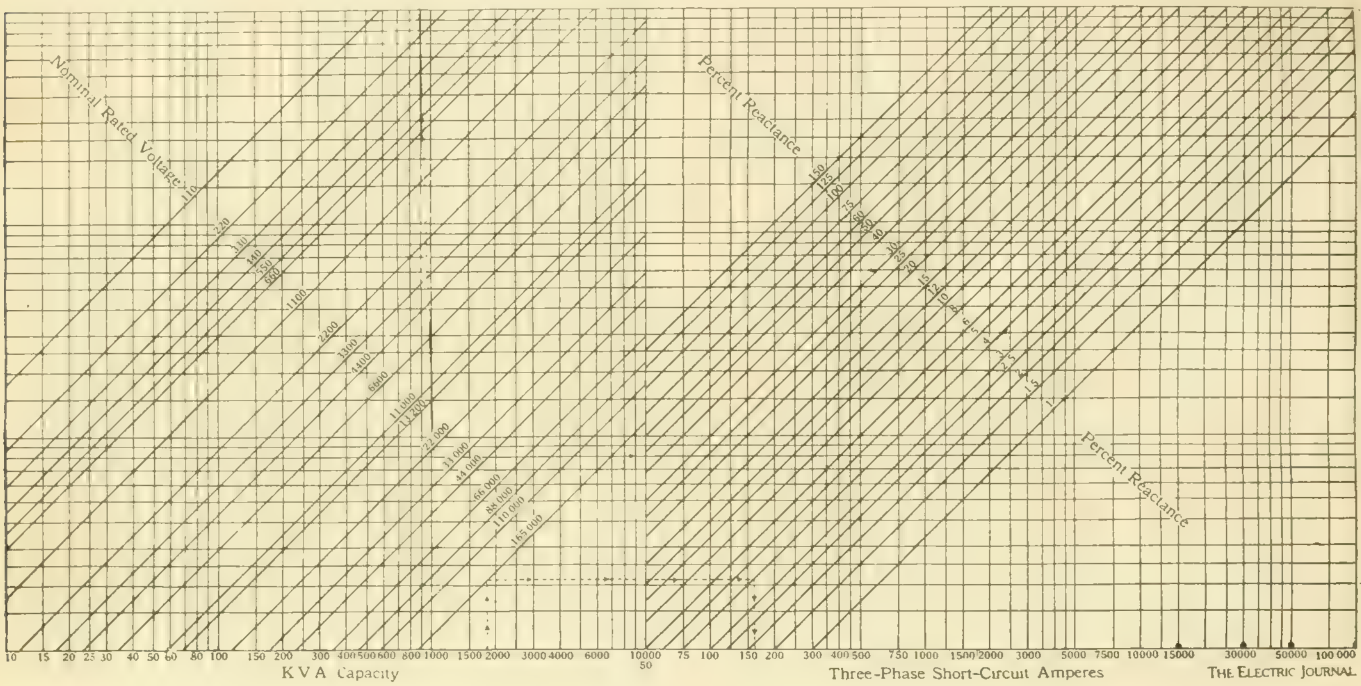


FIG. 14—CHART FOR ESTIMATING SHORT-CIRCUIT CURRENTS AT ANY GIVEN VOLTAGE AND PERCENT REACTANCE

To estimate the current in a three-phase short-circuit, start with the k.v.a. capacity of all synchronous apparatus connected, read vertically upwards to the diagonal line representing the voltage, thence read horizontally to the right to the diagonal representing percent reactance between the short-circuit and the source of power, thence vertically downward, the figures at the bottom of the chart giving the short-circuit amperes in each phase. The dotted line with arrow heads indicates the working out of a typical example.

TABLE I—MINIMUM TIME IN SECONDS

Between the instant of short-circuit and the parting of the contacts for different relay combinations.

No Relay		Solenoid or Motor Relay		Induction Relay	
A. C. Series Trip Coil	Cur. Trans. with A. C. Trip Coil	Cur. Trans. with A. C. Trip Coil	Cur. Trans. with D. C. Trip Coil	Cur. Trans. with A. C. Trip Coil	Cur. Trans. with D. C. Trip Coil
0.05	0.08	*0.10	*0.15	*0.20	*0.25

*If the circuit breaker is equipped with undervoltage release mechanism use 0.08 sec.

EFFECT OF AUTOMATIC VOLTAGE REGULATORS

Automatic voltage regulators increase the excitation after a short-circuit in the endeavor to hold normal voltage on the bus-bars. The maximum current which can be obtained from the exciters will not ordinarily be more than fifty percent greater than that required at full-load, eighty percent power-factor. Under short-circuit the alternator terminal voltage is reduced, hence the resultant flux density in the alternator iron is also reduced. A given increase in excitation therefore produces a proportionate increase in current flowing in the short-circuit. Hence if the excitation increases fifty percent the sustained short-circuit current will be approximately fifty percent greater than the sustained current due to full-load eighty percent power-factor excitation.

An appreciable time, however, is required for the excitation to increase to its maximum value. During the first half second the amount of short-circuit current is not affected by the presence of the voltage regulator but from this time on the current curve is higher, reaching a value at the end of two or three seconds of fifty percent greater than the current without the regulator.

An exception to the above appears when the external reactance is so high and the short-circuit current so limited that the regulator is able to maintain normal voltage at the generator terminals. In such cases the sustained current may not be increased as much as fifty percent but will be limited to the current which will pass through the external reactance with normal voltage impressed upon it.

PRECAUTIONS

Future extensions to a given system should not be overlooked in selecting the circuit breaker, therefore, it will be necessary to approximate the size to which the system may grow in a reasonable time and to make suitable allowance for such growth.

Nonautomatic trip recommendations are usually based on the assumption that the circuit breaker is in good operating condition, that its contacts will not part within less then 2.0 seconds after the maximum instantaneous current produced by an unexpected abnormal circuit condition has been reached, and that their parting is not impeded. The maximum time that the circuit breaker should carry an abnormal current depends on its thermal capacity. Based on the 2.0 second application this time is 5.0 seconds.

Automatic trip recommendations are usually based on the assumption that the circuit breaker is in good operating condition and that its contacts will part in not less than a stated minimum time after the maximum instantaneous value of the abnormal current has been reached. Any faulty condition of the breaker, such as poor oil, stiff bearings, sluggish operation or accumulation of dust will diminish the interrupting ability. Also if the contacts part in a shorter time than the stated minimum, a larger circuit breaker will be required, while if the contacts part after a greater time than the stated minimum value a smaller circuit breaker may be used.

Relays may be used to delay the parting of the oil circuit breaker contacts after the start of an abnormal current. The greater the delay, the less, in general, will be the current to be interrupted. Hence, by inserting a suitably adjusted time delay relay, a given automatic oil circuit breaker may be used on a larger system, or for a given system, a smaller circuit breaker may be used. Minimum trip time values for the usual combination of relays and oil circuit-breaker trips are given in Table I. In applying them, it must be remembered that the current-transformer trip combination with relays requires circuit opening relays, and the shunt trip combination requires circuit closing relay attachments.

Industrial Controllers - XXIII

Protective Devices

H. D. James

INDUSTRIAL controllers are commonly provided with one or more protective devices, such as overload, low voltage release, etc. Some of these devices are designed to protect the motor against abuse; others are for the protection of the operator or the machinery driven by the motor. The more common devices are for protection against:—

1—Overload
2—Low voltage
3—Phase reversal
4—Phase failure
5—Shunt field failure

OVERLOAD PROTECTION

Fuses—The oldest form of overload protection is the fuse, consisting of a strip of metal in the main circuit which is melted or fused when the current exceeds a predetermined value. The earlier forms of fuse consisted of an open link. A better and more accurate fuse was obtained by enclosing the fusable link so as to give it a more definite time element and prevent the particles of molten metal from dropping on surrounding objects. Fuses are easy to obtain in the ordinary sizes, as they are carried by most supply houes. Small fuses are inexpensive where only occasional overloads are experienced. Where the motor is worked hard resulting in repeated blowing of the fuse, the cost of fuse renewals, even for small motors becomes excessive and it is cheaper to use some form of overload device which does not require renewal. A knife switch should be provided for disconnecting the fuses from the line before they are renewed. Even the best designs of fuse are not very accurate, so that it is necessary to overfuse a motor somewhat to be sure of having a fuse of suffi-

cient capacity. The inherent time element in a fuse is a distinct advantage on a motor load, as the fuse will not respond to momentary variations in load, although it will act promptly on excessive overloads.

Circuit Breakers—The circuit breaker is a switch provided with an overload trip which usually consists of a magnet with a movable core. The attraction of the core of the magnet trips the circuit breaker and opens the circuit. Usually the current at which the circuit breaker trips is adjusted by changing the air-gap between the core and its pole face. Most circuit breakers are reset or closed by hand, although magnetic reset can be provided. No new parts are required for reestablishing the circuit after the circuit breaker has opened. The continual rupturing of the circuit gradually wears away the arcing trips of the circuit breaker so that these must be renewed occasionally. The overload trip can be provided with a dashpot for giving it a definite time element, which should always be done for motor loads.

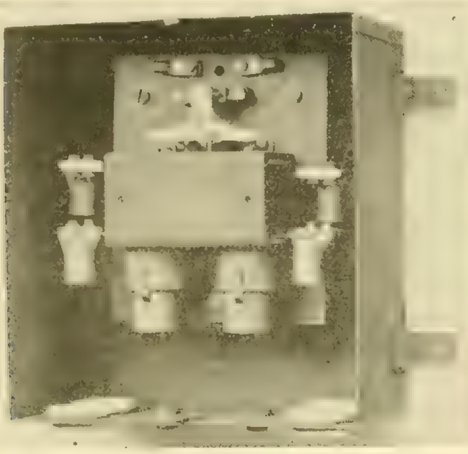


FIG. 1—DASH-POT TYPE OF INVERSE TIME ELEMENT OVER-LOAD RELAY

Overload Relay—The overload relay is a small circuit breaker which is actuated by a magnet and opens the circuit to the operating coil of a magnetic contactor or to the low voltage coil of a circuit breaker. The relay closely resembles the overload mechanism of a circuit breaker, with the addition of the small contacts referred to above. These relays should be provided with dashpots to give an inverse time element when used with motors. When the overload relay is used in connection with magnetic contactors arrangements can be made for reestablishing the electric circuit from a push button or master switch. When the relay trips its pilot circuit, this circuit may be maintained open by a mechanical latch on the relay or it may be opened through an electrical interlock on the magnet contactor. If a mechanical latch is used on the relay, this latch may be released either by hand or by another small magnet. The two methods are known respectively as "hand reset" and "magnet reset." Where the circuit through the relay contacts is opened on an interlock attached to the main contactor or through another relay, the device is known as "electrically reset". The hand reset on the relay is not recommended for most applications, as it is not desirable for the operator to place his hand near the live parts on the control panel.

Time Element Overload Relays—Engineers have recognized for years the desirability of having an overload device which would have a time element proportional to the time required to heat up the motor to a definite temperature with various loads. Such a device would give overload protection to the motor but would not protect the motor from a short-circuit or severe overload. This, however, could be readily taken care of by a fuse, as it would not be called upon to operate except in cases of emergency. Many motors are operated on intermittent loads, such as cranes, hoists, machine tools, elevators, etc. The motor is capable of carrying a heavy overload for a short period of time. This period of time is much longer than given by the time element in commercial forms of relays. It is necessary, therefore, to set the relay so as to prevent its operating on these short time overloads. This results in the motor being without adequate overload protection in case of prolonged operation at the maximum load. Large units, such as turbogenerators, have thermocouples incorporated in their windings. These thermocouples are connected to suitable switchboard instruments to indicate the temperature of the windings so that the load can be regulated properly. The same device could be used for opening the circuit breaker, if desirable. These thermocouples, however, are expensive and the apparatus required too elaborate for ordinary motor applications. There is therefore a field still open for the development of a long time overload device which will permit the motor to operate at a heavy load for relatively short periods of time and still protect the motor against continuous operation at this load.

FIG. 2—INDUCTION TYPE, TIME ELEMENT OVER-LOAD RELAY

Fig. 1 shows a commercial form of overload relay having a dashpot to give it an inverse time element feature. Another form of relay, shown in Fig. 2, has a copper disc rotating between the poles of permanent magnets to provide a definite time element. The dashpot type of relay is usually designed to give an inverse time element on increasing loads. Sometimes it is operated from series transformers with saturated cores

to give a constant pull regardless of the load. This latter form of relay is known as a fixed time element relay. It is the preferable form to use in connection with a controller which is connected to a large power supply line and is provided with a separate feeder circuit breaker for taking care of short-circuits.

Some operators are under the impression that it is desirable to adjust the time element of overload relays. This adjustment would be desirable if a long time element were obtained. Commercial forms of relays do not afford a time element which compares in length to the time required to heat up even small motors. It is desirable, therefore, to obtain as long a time element as possible with the dashpot relay and any adjustment provided should be set to give the maximum time element. If too long a time element is attempted with the dash-pot relay, there is a tendency for it to stick under adverse conditions. It is necessary, therefore, to adjust this time element so that the maximum time given will insure satisfactory operation.

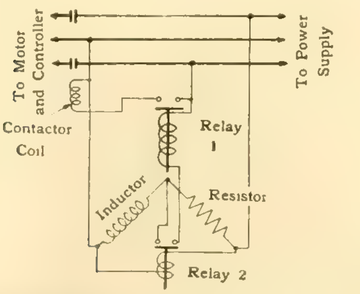


FIG. 3—COMBINED PHASE FAILURE AND PHASE REVERSAL RELAY FOR A THREE-PHASE CIRCUIT

This consists of two small relays, the contacts of which are closed by electromagnets. Relay *2* is connected across one phase of the circuit and remains closed as long as that phase is energized. The coil of relay *1* is connected between the three phases of the circuit, one end of the coil having an inductor in one branch and a resistor in the other branch. This combination brings the current in the two branches of the circuit so that its effect upon the coil of relay *1* is added when the phase relation is correct. On a reversal of phase relation, the current in the two legs of the circuit through the coil of relay *1* oppose each other and the relay drops open. On failure of voltage in any one of the three phases, relay *1* is opened either directly or through the opening of relay *2*. The contactor coil for the control is in circuit with the contacts of relay *1* so that the opening of this relay disconnects the motor from the line.

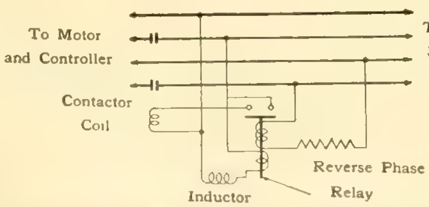


FIG. 4 COMBINED PHASE FAILURE AND PHASE REVERSAL RELAY FOR A TWO-PHASE CIRCUIT

This device consists of a single relay having two coils, the coil across one phase having a resistor in circuit with it. The coil across the other phase has an inductor in circuit with it. The use of the resistor and inductor in the two coil circuits results in the current in each coil being approximately in the same phase relation and their action is added. If, however, the phase relations of the supply circuit are reversed, the magnetic action in the two coils is opposite and the relay opens. On failure of voltage in either circuit, one coil is de-energized and the relay opens. The coil for the magnetic contactor for the main circuit is connected through the contacts on this relay so that when the relay opens the magnet contactor coil is disconnected, opening the contactor and disconnecting the motor from the line.

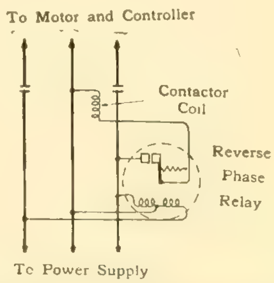


FIG. 5 - COMBINED PHASE FAILURE AND PHASE REVERSAL RELAY OF THE WATTMETER OR MOTOR TYPE

The coil for the contactor in the motor circuit is connected through the contact in the relay. This contact is held open by a spring and is closed due to the torque exerted by two coils connected to two of the three phases. These coils set up a motor action which forces the contacts together against the spring pressure when the phase relation is correct. If either of the three phases is reversed the torque on the watt meter movement is reversed and the contact opens. If the voltage fails in either phase, the torque is reduced to zero and the spring opens the contacts.

All motor circuits should be protected by feeder circuit breakers or fuses. If the feeder circuit is connected to a very large transformer or to a power circuit having large capacity back of it, the feeder circuit breaker should be of ample capacity to take care of the power ahead of it in case of a short-circuit to the feeder or the apparatus connected to this feeder. This circuit breaker must have a less time element on its trip than that obtained with the overload relay on the controller panel. This latter will require a relay with a fixed time element to insure the opening of the circuit breaker before the contactor on the control panel. The circuit breaker can be set for a high enough value so that it will not be affected by ordinary overloads. The overload device on the control panel should be set low enough to protect the motor against abuse. Where overload relays are used in connection with feeder circuit breakers, it is desirable to have an adjustable time element. In many cases the same overload relay is used for both classes of service. It is therefore provided with an adjustable time element, although the short time element is not desirable when used on the controller.

LOW VOLTAGE PROTECTION OR RELEASE

Devices of this kind are arranged for disconnecting the motor from the line on failure of voltage. The Electric Power Club has recognized two forms of this protection:—

(a) *Low Voltage Release*—This provides for disconnecting the motor from the line on failure of voltage, but permits the motor to start automatically when line voltage is re-established. Such a device is the magnetic contactor control with automatic acceleration. It is used for pumps, fans, and similar applications which should restart automatically when the voltage is restored to the line.

(b) *Low Voltage Protection*—This device disconnects the motor from the line on failure of voltage and prevents the motor from being started again on re-establishment of line voltage. In order to start the motor, the operator must push a button or operate a lever. This latter is a very necessary precaution where the motor is used for driving machine

tools or woodworking machinery, printing presses or in fact, any device which might cause injury to a person working on the machine.

These devices are sometimes known as "under voltage" instead of "low voltage", both terms having the same significance. Usually they do not respond to a small drop in voltage.

PHASE REVERSAL PROTECTION

This device operates to disconnect the motor from the line in case one of the phases of the polyphase circuit has been reversed. Such reversals sometimes occur when repair men are installing service transformers or making other repairs. The effect of such a reversal is to cause the motor to operate in the opposite direction. For some applications such a reversal will not cause any damage, but where the motor drives an elevator or hoist a serious accident may result. Some public service corporations supplying electric power to users require the installation of a reverse phase relay device on all elevator motors to perfect them from liability resulting from such an accident. There are a number of these devices now in the market. Some of them consist of a small relay having two parts corresponding to the stationary and movable element of a motor or wattmeter. Power supplied to these two parts causes rotation in a definite direction. The torque thus established maintains a contact in the closed position and represents normal operation. If either phase is reversed, the torque of the relay is also reversed which opens the contact and disconnects the control and motor from the line.

Another form of relay is shown in Fig. 3. This relay is made up of standard contactors. The operating coil is supplied through two circuits, as shown. One of these circuits has a resistance in series with it, the other an inductance. The resistance and inductance cause a displacement between the two phases so that their affect is added and the relay maintained closed. If either phase is reversed, the phase angle is changed, causing the two circuits to oppose each other, reducing the magnetic action on the coil and opening the relay. In the case of the two-phase arrangement shown in Fig. 4, the contactor is provided with two separate coils, one in each phase.

Some devices of this character have been designed to close a circuit on reversal of phase rather than open it. Such devices have special applications in connection with power circuits, but are undesirable for industrial control as the failure of the contacts to make a good electrical connection or the breaking of one of the wires would prevent such a device from operating. Where the contact is closed for normal operation, the breaking of a wire or the failure of the contact would disconnect the controller from the line and automatically stop the motor, which is a safer arrangement.

PHASE FAILURE PROTECTION

Sometimes one line of a polyphase circuit may be opened accidentally. If the motor has not started, it will fail to do so and may be injured by leaving it connected to the line. This can easily happen in a mechanically-operated elevator control where the failure of the motor to start might cause the operator to leave the controller in the running position. By using a low voltage device across two phases of the three-phase circuit, or one relay for each phase of the two-phase circuit, the motor can be protected from such an accident. The relays are connected in such a way that the main switch will not close until both relays are closed. This arrangement is often combined with a phase reversal relay device to give protecrion to the elevator both from phase reversal and phase failure,

If a motor is rotating and one phase is opened, the motor will continue to operate single phase if the torque does not exceed the single-phase torque of the motor. Such operation, however, causes all of the load to be carried by one phase of the motor and may seriously overheat these windings. If the overload protection is set at a low enough value, it will protect the active phase from an excessive overload. Unfortunately, such overload devices are frequently set too high to afford proper protection. While the motor is operating, voltage is maintained across all three terminals of a three-phase motor or across both phases of a two-phase motor, due to the active phase generating voltage in the inactive circuit. The voltage generated in the inactive circuit is very little less than the normal voltage, so that any phase failure device depending upon a drop in voltage for operating it will not respond, when connected to a rotating motor. Fortunately many installations, such as elevators, hoists, etc. operate for only a short time with out coming to rest, so that a phase failure device will operate the first time the motor is brought to rest and prevent restarting it.

SHUNT FIELD FAILURE

Shunt-wound direct-current motors may operate at an abnormal speed and destroy themselves by centrifugal action if the shunt field becomes disconnected from the line. While this kind of an accident is of very rare occurrence, it is thought advisable to guard against it in some particular cases. The usual method of guarding against this form of accident is to provide a relay and place its magnetic circuit in series with the shunt field circuit of the motor. When this relay is energized, it closes the pilot circuit to the controller. If the shunt field circuit should open, this relay will open the pilot circuit to the controller, which in turn disconnects the motor from the line.

One serious objection in the use of this relay is the transformer action which takes place in the motor due to sudden changes of load. This action is particularly noticeable when the motor is compound wound. A rapid change in load causes a change in the field flux. This exerts a transformer action on the shunt field

windings and may be sufficient to momentarily reverse the current in these windings. This does not mean that the flux in the field circuit of the motor is reduced to zero. It simply means that the rate of change of the flux is sufficient to generate a counter voltage in the shunt field windings large enough to cause a momentary pause in the current through these windings. This is not very hard to do as the shunt field usually has a very large number of turns, which multiplied by a small change in flux, will cause a considerable voltage. A reaction of this kind in the shunt field circuit of the motor may cause the relay to drop out and disconnect the motor from the line. The connections to the controller are such that when the relay does open the circuit, the motor will not start again automatically. It requires action on the part of the operator to reset this relay.

A number of devices have been used to delay the action of this relay to prevent an interruption of service. One method consists in adding considerable inertia to the moving parts of the relay by means of a pivoted weight or similar device. Another method is to use a heavy tube of copper around the magnet core. This copper tube acts as the short-circuited secondary of a transformer and delays any change in magnetism in the relay. Usually one or the other of these devices will prove satisfactory, although in aggravated cases, additional precautions must be taken.

Engineers, as a rule, do not consider it necessary to use a shunt field protective relay except with large motors which may run light under certain conditions of load. Safety devices of any character should be avoided where unnecessary, as they add complication to a control equipment and require additional inspection and care to maintain in an operative condition. It is seldom that any safety devices are used other than overload and low voltage. Wherever a safety device is used, it should be tested at frequent intervals to insure its proper operation in case of accident.

Changing a Direct-Current Machine to a Synchronous Converter

M. W. SMITH

THE FOLLOWING discussion is intended to show the relations between a direct-current machine and a synchronous converter and, in a general way, to show the possibilities and difficulties in changing a direct-current machine to a synchronous cenverter. It is not possible in the scope of this article to cover each particular case and combinations of windings but the principles and relations here shown should apply, when given the proper consideration.

EXCEPT for certain relations which exist between the alternating and direct-current sides of a synchronous converter, its design is essentially the same as that of a corresponding direct-current machine. The armature winding, in addition to being suitable for connection to the commutator, must also be arranged for connection to alternating-current collector rings. The armature windings are usually straight multiple and series or two-circuit types, while the windings of direct-current machines are sometimes various modifications and combinations of these. However, it is sufficient for the purpose of this article to consider only the straight multiple and two-circuit windings. On account of its limited current capacity the two-circuit winding is used only for small or slow-speed machines where a large number of conductors are required in order to get the desired voltage.

RATIO OF COILS TO COLLECTOR RINGS

In either the multiple or two-circuit winding, the alternating-current taps must be made in such a way as to have the armature winding electrically balanced, i.e., there must be the same number of electrical degrees (and hence conductors) between adjacent taps. For the multiple winding, there must be one tap for each collector ring per pair of poles. Therefore, assuming all the alternating-current taps made on one side of the armature, the number of coils, and hence the number of commutator bars per pair of poles, must be a multiple of the number of collector rings. For the two-circuit winding, only one tap is necessary for each collector ring to the whole armature winding, regardless of the number of poles. Then with all the taps on one side of the armature, the total number of coils (and hence commutator bars) must be a multiple of the number of collector rings. By making some of the alternating-current taps on the commutator end of the machine, and bringing the collector leads through the spider, the armature winding, for either multiple or series-wound ma-machines, may be symmetrically tapped when the number of conductors, instead of the number of coils, is a multiple of the number of collector rings. This scheme is undesirable and should be avoided if possible, especially on the larger machines.

The fact that the alternating-current taps have the same number of conductors between them does not always mean that there are the same number of slots and teeth between taps. Hence, at the same instant taps which have the same phase position may not have the same total flux between them, due to the difference in the magnetic reluctance. This magnetic unbalancing has a tendency to cause vibration, which will probably not be objectionable on small machines, but may be sufficient on larger machines to cause the brushes to chatter and impair comutation. The number of collector rings required for the different number of phases is as follows:—

Single-phase	2
Two-phase	4
Three-phase	3
Six-phase	6

CHANGE OF SPEED

Tapping the armature winding as outlined is about the only change in the winding necessary when changing over a direct-current machine to a synchronous converter at the same speed and voltage, and using the old windings and commutator. This, however, is a condition seldom met in practice. The speed of a machine with a given number of poles will, of course, be determined by the frequency of the applied alternating-current voltage, i.e., the machine will run at synchronous speed corresponding to the applied frequency, which equals 120 times the frequency divided by the number of poles. It is very often this fact which prevents the conversion of a direct-current machine to a converter of the desired frequency. Direct-current machines are usually designed for an overspeed of about 25 percent, and sometimes the mechanical design is not liberal enough to stand this speed continously. Therefore, it will rarely ever be possible to run a direct-current machine as a converter at a frequency which corresponds to a speed greater than 25 percent above normal, depending on the mechanical design. The stresses at the desired speed should be carefully checked in each particular case, and especially when the machine is to run inverted, i. e. direct to alternating-current or under any other condition where an overspeed is liable to occur. The frequencies of direct-current machines vary over a considerable range, usually from 10 to 45 cycles, while the frequencies of synchronous converters are usually confined to 25 and 60 cycles, which are the standard frequencies in this country. Therefore, the chances of converting a direct-current machine to a 60-cycle converter are rather remote, but 25 cycles is well within the above limits.

The commutator of a direct-current machine is designed for a certain voltage and a certain current and neither of these limits can be appreciably exceeded, the extent to which they can be exceeded safely depending on the margin in the particular design. As stated above, it may be possible to run a direct-current machine as a converter at a speed 25 percent above normal. Then, keeping the same flux densitites in the machine, this would mean a voltage 25 percent above normal which might be higher than the commutator would stand from the standpoint of flashing. Ten to fifteen percent above normal would be a better limit. For such a small difference, it would hardly be feasible, or even possible, to put a new winding in the machine to bring down the voltage within the limit. The field excitation, and hence the flux densities, should be reduced so as to give the desired voltage. Although the commutating characteristics at the higher speed and frequency will not be quite so good, the machine will probably be able to carry approximately the same current output.

VOLTAGE CHANGES

When changing the machine to a converter of a frequency corresponding to a speed below the normal value, the current output will be the limiting feature rather than the voltage. The value of the current should be the same at the reduced speed as before. Using the same windings and working the machine at the same inductions, the voltage and hence the rating will be reduced directly as the speed. It is sometimes possible to change the armature winding and keep the voltage the same at the reduced speed as before. This, however, is not often possible for small changes in speed, as the right number and combination of conductors cannot be obtained with the existing number of slots and commutator bars. But for large changes in speed, it is sometimes feasible.*

For instance, suppose a direct-current machine wound with a single-turn coil, and a multiple winding is to be run as a converter at a frequency corresponding to half the normal speed. By rewinding the machine with a two-turn coil and a multiple winding, the same voltage as before may be obtained. However, the current and hence the rating of the machine must still be reduced in the ratio of the speed; i.e., half the original value.

Since the armature heating of a polyphase converter is less than that of a corresponding direct-current machine, as explained later, it might be expected that the current could be increased above one-half the original value (even though the conductors are only approximately one-half their original size) and partially restore the original rating. However, commutating conditions prevent this due to the increased reactance voltage under the brush incident to the increased current. Hence, so far as the rating of the machine is concerned, there is no advantage in changing the voltage, except to adapt the machine to the desired circuit voltage. Of course, it may not always be desirable to keep the voltage the same, even though the speed remains the same. In any case, the same problem presents itself, i.e., on account of the small number of conductors per slot and with a given number of commutator bars, it is hardly possible to rewind a direct-current machine for small changes in voltage. For a change in voltage of two or three to one, etc., it is sometimes possible to get the desired change in voltage, provided the change does not exceed the limit of the commutator. For instance, on a machine wound with one two-turn coil per slot, or two single-turn coils per slot, it would be possible to reduce the voltage to one-half, keeping the speed and induction the same, by rewinding the machine with a one-turn coil per slot. It would then be necessary to parallel each alternate commutator bar with the one adjacent to it, so as to have one-half the number of active bars as before. Since the current must be kept the same as before, the rating will be reduced to one-half its original value.

Since the converter has only one armature winding, with the commutator on one end and the alternating-current collector rings on the other, the ratio between the alternating and direct-current voltages is

*See article on "Adapting Direct-Current Motors to Changed Conditions" by H. L. Smith in the JOURNAL for April, 1916, p. 177.

fixed, and is practically constant at all loads. Unlike a direct-current generator, changing the field excitation will not change the direct-current voltage (assuming constant alternating-voltage), but as in the case of a synchronous motor, changing the field excitation causes reactive current to be drawn from the line to magnetize or demagnetize the field, depending on whether it is under-excited or over-excited, so as to keep the air-gap flux, and hence the generated voltage, constant. The approximate ratios of the alternating-current voltage to the direct-current for the different number of phases are as follows:—

Single-phase	0.71
Two-phase diametrical	0.71
Three-phase	0.62
Six-phase double-delta	0.62
Six-phase diametrical	0.71

ARMATURE HEATING

The alternating and direct-currents tend to flow in opposite directions in a synchronous converter armature winding, and the actual current in the winding is the resultant of the two. The resultant current and hence the heating, varies in different conductors on the armature, and for different power-factors. At unity power-factor, it is a maximum in the tap coil and decreases to a minimum value in the coil midway bebetween taps. If the power-factor of a converter is reduced below unity, the alternating-current not only increases, but its distribution also changes and the armature heating, especially in the tap coils, increases very rapidly. Therefore, it is desirable that the field excitation on the converter be adjusted so as to maintain unity power-factor. The average heating over the whole armature of a machine, when operated as a converter at unity power-factor, compared with the armature heating of the machine when operated as a direct-current generator with the same output (assuming four percent losses in the converter) is as follows for machines of the different number of phases:—

Direct-current generator	= 1.000
Single-phase converter	= 1.475
Two-phase converter	= 0.385
Three-phase converter	= 0.585
Six-phase converter	= 0.275

From the above comparison, it is evident that, except in the case of the single-phase converter, the armature heating will never be the limiting feature when changing a direct-current machine to a converter. On account of the numerous single-phase lighting systems, the single-phase converter is often desired, and in this case the heating limit is an important feature.

COMMUTATING POLE FLUX

The commutating-pole ampere-turns on a commutating-pole direct-current machine serve two purposes:—they must be sufficient to buck down the armature magnetomotive force between poles; and they must further be strong enough to force enough flux across the commutating-pole air-gap to generate sufficient e.m.f. in the short-circuited coils undergoing commutation to counterbalance the reactance voltage generated in the coil due to the reversal of the armature current in this coil. In a converter, the commutating conditions are practically the same as those in a direct-current machine, except that the component of the ampere-turns on the commutating-pole field required to buck down the armature ampere-turns is less. This is due to the fact that the alternating and direct-currents in a converter tend to flow in opposite directions in the windings, and the resultant armature m.m.f. is the difference in the direct and alternating-current m.m.f's, which tend to be produced. Therefore, the strength of the commutating-pole field on the direct-current machine which is to be changed to a converter will be too, strong, and the flux density in the commutating-pole air-gap will be too high. Thus, it will be necessary to increase the commutating-pole air-gap so as to use the excess ampere-turns on the commutating-pole in forcing the flux across the longer air-gap keeping the same density in the air-gap at a given load as before. The proper air-gap can best be determined from test. It is, of course, possible to shunt part of the current from the commutating-pole winding instead of increasing the air-gap, but the latter is usually preferable. In the case of a non-commutating-pole direct-current machine, no change will be necessary, and since the resultant m.m.f. between poles, and hence the distortion of the main field, will be less when changed to a converter, the commutating characteristics should be even better.

DAMPER WINDINGS

A synchronous converter is usually equipped with a damper winding, and started from the alternating-current side, as an induction motor, by the application of reduced voltage, and then connected to full voltage, when up to speed. A direct-current machine is not equipped with a damper winding, and hence when changed to a converter, it could not be started from the alternating-current side unless such a winding is added. It would be necessary to start the machine from the direct-current side, or by some external means such as a starting motor. In either of the two methods it would be necessary to synchronize the converter before connecting it to the alternating-current circuit. However, even if the machine can be started from the direct-current side or by some external means, it should be provided with damper windings so as to prevent or reduce to a minimum the liability of the machine to hunt. If the converter is to carry a steady or slowly varying load it will probably operate satisfactorily without damper windings, but if it supplies a fluctuating load or is connected to a system on which the voltage is not steady, it may hunt badly or even fall out of step.

On account of the difficulty and expense, it is usually almost out of the question to consider making the necessary changes to equip a direct-current machine with damper windings. On some of the later types of direct-current machines which are equipped with compensating windings in the pole faces it might be possible to short-circuit this winding and have it serve as a damper winding. On account of its low resistance the damping action should be good, although it might not be satisfactory for starting purposes.

SUMMARY

The following conditions are necessary before a direct-current machine can be changed to a synchronous-converter by the addition of slip rings.

a—If it has a multiple wound armature, the number of coils and hence the number of commutator bars per pair of poles must be a multiple of the number of collector rings. If it is a series wound armature only the total number of coils and hence the total number of commutator bars need be a multiple of the number of collector rings. An undesirable alternative is possible when the number of conductors per pair of poles for multiple windings, or the total number of conductors for series windings, is a multiple of the number of collector rings.

b—The speed of the machine should be reasonably close to its synchronous speed as a converter. Operation much above normal speed is unsafe. If operated below normal speed, the capacity is reduced in proportion to the speed reduction.

c—The rated voltage of the machine should be reasonably close to the desired direct-current voltage of the converter, or to an even multiple thereof. In the latter case, the armature must be rewound, or reconnected. It is impracticable to raise the voltage per commutator bar.

d—If changed to a single-phase converter, the allowable armature current is reduced.

e—The commutating pole excitation must be reduced.

f—A damper winding is desirable to minimize hunting, and is essential for starting from the alternating-current side, but is difficult to install.

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OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1658—INDUCTION MOTOR WINDINGS—I have noticed a number of motors recently with an insulated ring around all the coils on the opposite side from the end connections. Will you explain what it is there for? (a) Is it to prevent the coils from spreading outward or from being drawn inward? (b) Is it very necessary? (c) If so, why is it not necessary to have them on both sides?

C.E.A. (MASS.)

(a) It is to prevent mechanical movement in the coils when there are large currents flowing, as for example in starting up from rest. (b) It is found to increase the life of the coils very considerably. (c) On the connected end the cross connections themselves form somewhat of a brace and the supporting ring is sometimes omitted on that end. In other cases where the coil throw is long or the coil is not mechanically rigid the supporting rings are placed on both ends. A.M.D.

1659—COMPENSATOR OIL—I would like to know what is the best grade of oil used in 220 volt compensators and where it can be obtained. I have had some trouble with contacts burning off and think this is due to poor grade of oil or a change of oil being necessary. How often should oil be changed? These starters range from 10 to 50 hp.

G.C.H. (ILL.)

The best oil for use in starters for squirrel cage motors is a mineral oil with a high flash and fire point and an oil which is free from any trace of acid or alkali. A low factor of evaporation is desirable and the oil should give little deposit under operating conditions. The Westinghouse Company recommends "HF" oil for use with autostarters. This oil meets the requirements outlined above. It is unlikely that the burning of the contacts is due to the oil used unless the oil is allowed to fill up with a large amount of sediment. Burning of the contacts is more often due to severe operating conditions, abuse of the starter, misapplications and is also affected materially by the design of the contacts and the contact action. A certain amount of burning or pitting of the contacts is unavoidable even under the best conditions. As a general rule the oils should be changed when sediment begins to collect on the tank bottom and the oil turns dark in color. R.E.C.

1660—FAN-MOTOR WINDING—Fig. (a) shows a six-pole direct-current machine with an uneven number of commutator segments and slots. The machine is a large fan motor and as I have been unable to find a suitable winding I would be very glad if you could indicate to me the correct type of winding to employ. E.T.A. (CAN.)

This motor should be wound with a two-circuit winding, the coils being

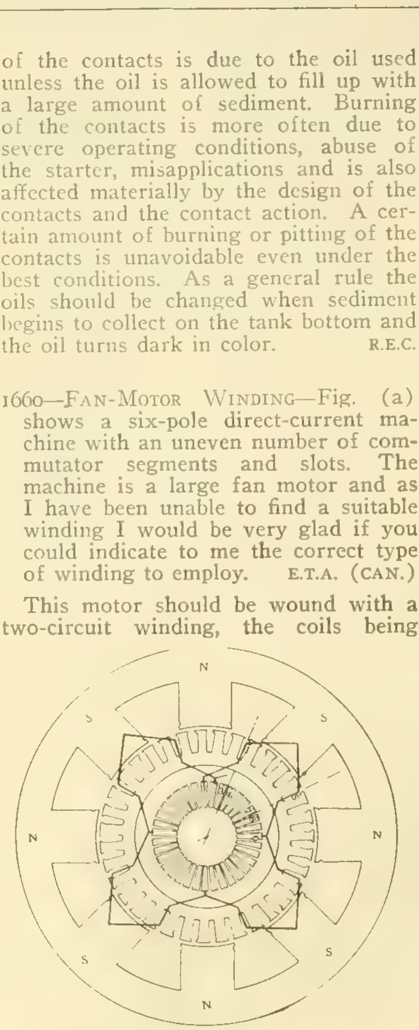

FIG. 1641(a)

placed in slots 1 and 5. The ends of the coils should be connected to commutator bars 1 and 10. Fig. (a) shows four coils and gives the relative numbering of the slots and bars. With the two-circuit winding shown either 2, 4, 6 or 8 brushes can be used providing they have sufficient capacity for the rating. These brushes must of course be placed 45 degrees apart.

G.H.G.

1661—CHOKE COIL—In general what determines the voltage rating of a choke coil and what would be the effect of using a choke coil of a higher voltage than the line voltage. For example, given a 6600 volt ungrounded 60 cycle circuit, what would be the proper voltage rating of a choke coil for use with a lightning arrester, and what would be the result of using a choke coil whose voltage rating is 25 000 volts? W.C.A. (MO.)

The voltage rating of a choke coil used for lightning protection ordinarily has no reference to the coil itself, but depends only on the insulators by which it is supported. Examination of the catalogs of the manufacturers of such coils will show that the same coil is used over a wide range of voltages, but supported by different insulators. Several different sizes of coils are on the market, it is true, but the smaller ones are of little value from a protective standpoint. The larger coils listed are not too large for any commercial application from a protective standpoint, but from a commercial standpoint, they are often considered too expensive an investment for the smaller circuits. The use of smaller coils on these circuits can sometimes be justified from an engineering standpoint by the fact that these circuits are less exposed to severe lightning disturbances, but where they are used on large systems, or to protect expensive apparatus it is a short-sighted form of economy. Where extra large

or double coils, are listed for high-voltage circuits, it is because the value of the apparatus to be protected practically always warrants the larger investment in choke coils. The use, therefore, of a large or high-voltage choke coil on a small, or low-voltage circuit, will give good protection, and be advisable from every standpoint, except that of cost. Of course the use of unnecessarily large insulators can do no harm. Q.A.B.

1662—NUMBER OF ROTOR BARS—Please define the relations between the number of rotor bars used in an induction motor and the frequency of the alternating-current supply. G.L.H. (ILL.)

There is no relation. The number of rotor slots follows from the number of stator slots which are determined by the number of poles and the voltage of the motor. B.B.R.

1663—TRANSFORMER CONNECTIONS — In the case of a bank of three single-phase transformers connected as in Fig. (a), delta-star, the primary being lettered as shown, what would the secondary lettering be? How is this relationship determined? Also in the reverse case, star-delta? S.E.H. (PA.)

The leads of each single-phase transformer have their own standard markings but there are no standard methods of marking the connections of a bank of single-phase transformers to a three-phase line. According to the latest rules of the N.E.L.A. and Electric

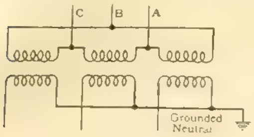

FIG. 1663(a)

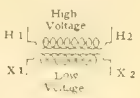

FIG. 1663(b)

Power Club, the leads of each single phase transformer would be marked as shown in Fig. (b). The markings are so applied that, if voltage is applied to *H1* and *H2*, with *H2* and *X2* connected together, the voltage between *H1* and *X1* will be less than that between *H1* and *H2*. W. M. M.

1664—SINGLE-PHASE ROTARY CONVERTER —Please state the amount (in proportion) of ampere-turns used on the armature and shunt field of a single-phase rotary converter as compared with a direct-current shunt motor of same capacity. G.L.H. (ILL.)

The ratio of the shunt field to the direct-current armature ampere-turns on small machines ordinarily used as single-phase converters ranges from about 1 to 1.5. On a corresponding direct-current machine, this ratio would be about 1. Generally speaking, the ratio of the field ampere-turns to the direct-current armature ampere-turns on a single-phase converter is about 25 percent higher than the same ratio on a corresponding direct-current shunt motor. However, this is merely a matter of convenience in design, and the ratio could be varied over a wide range. M.W.S.

1665—MAGNETO VOLTAGE—What is the approximate voltage of a 50 000 ohm magneto? S.E.H. (PA.)

The voltage of the magneto will obviously depend on both the crank speed and resistance of the load. It will also depend upon the make. One particular type rated as a 50 000 ohm magneto, develops from 175 to 200 volts when connected to a resistance of 50 000 ohms. G. J.

1666—POTENTIAL TRANSFORMER FUSE—We have a 60 cycle, 0.2 k.v.a., 6600-110 volt potential transformer in use on an indicating wattmeter which reads up to 700 kw. What capacity fuse should be used with this transformer? W.C.A. (MO.)

The use of fuses on the high-voltage side of instrument voltage transformers is not primarily to protect the transformer but to protect the power system from any disturbance which might start in the transformer. With reference to the 6600 volt transformer, the high-voltage winding is in all probability smaller in carrying capacity than any commercial 6600 volt fuse, so that in case of any trouble the winding will be burnt out by the time the fuse opens. The fuses, however, keep the disturbance from being communicated to the power busses, thereby averting a short-circuit on the power system. With a rating of 200 volt-amperes, the full-load current on the 6600 volt side, even when considering the addition of the exciting current of the transformer is not over 0.05 or 0.06 amperes, therefore, the smallest capacity fuse available for a 6600 volt circuit will be suitable. If desirable, fuses may be placed in the low-voltage circuit from the transformer to protect it from short-circuits originating in crossed leads, etc., and since the current rating of the low-voltage winding is two amperes, a three-ampere, 110 volt fuse should be sufficient. The amount of power measured by the wattmeter with which the voltmeter is connected has no bearing on the question of application of fuses. See also article on "Protective Resistors for Instrument Transformer Fuses" in the JOURNAL for May, 1918, p. 180. W.E.D.

1667—INDUCTION MOTOR WINDING—I am lacing in several stator coils having two parallel No. 14 wires. I am having trouble getting them all in and I am wondering if I could not combine the cross-sectional area and use one No. 11 wire with the same number of turns. By doing this I save considerable room, and I would ask whether this procedure would affect the characteristics of the motor. If it does not with a few coils, would it make a difference to rewind the whole motor the same way? I.J.T. (PA.)

The No. 11 wire can be used instead of the two No. 14 wires in parallel, either for a few coils or for the whole winding, without altering the characteristics of the motor. In rewinding the complete motor it is easier to thread the coils through the slot opening after making up the coils, rather than use a long wire for each coil and lace the winding in from the end of the core. The No. 11 wire, however, may be too large to go through the slot opening and as the question of room does not come in, in threading in, it is better to use the two No. 14 wires in parallel, in rewinding the complete motor. B.B.R.

1668—FAN MOTOR WINDINGS—I have a 100 volt, 100 cycle fan motor for eight poles arranged as shown in Fig. (a) with eight coils connected in series as shown in Fig. (b), wound with No. 24 B. and S. copper wire with 175 turns per coil. Each pole has a starting coil wound with bare copper wire No. 18 B. and S. with 12 turns each, and in short-circuit. It gives only 650 r.p.m. when connected to a 50 cycle supply. Could you please tell me how can I rewind it so as to use it on a 50 cycle supply? A.A. (MEXICO)

This motor can be reconnected for 50 cycles by reversing the polarity of alternate pairs of poles as shown in Fig. (b). It is presumable that the starting torque will be poor with this arrangement. It will probably be improved by removing the starting (or shading) coil from every other pole as shown in Fig. (b). If the starting torque is still so

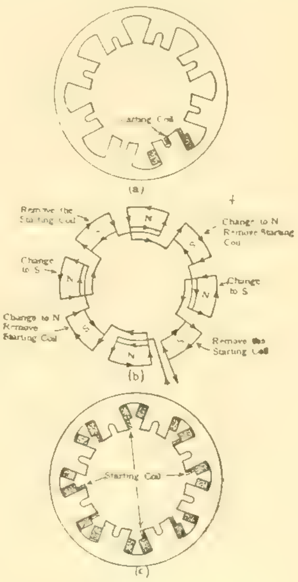

FIG. 1668(a), (b) and (c)

low that the fan needs to be started by hand, the torque will be still further improved by removing the starting coils completely from all the poles and winding new starting coils entirely around every other pole as shown in Fig. (c). C.R.R.

1669—TRANSFORMERS OF UNEQUAL RATIO IN PARALLEL—All other relations being correct, what would be the result paralleling the secondaries of two banks (of three each) single-phase transformers connected delta primary and star secondary with grounded neutral, there being a secondary voltage difference of 100 volts? Both banks are fed from a common 13 200 volt, 60 cycle bus in this manner. No. 1 bank, 6600 kw, 66 000/4000 volts being fed from a 13 200 volt bus by way of step up transformers and a 66 000 volt transmission line about 8 miles long. No. 2 bank, 600 kw, 13 200/3900 volts being directly fed from a 13 200 volt bus over a line about 8 miles long. S.E.H. (PA.)

A definite answer to this question would require a knowledge of the characteristics of the lines and transformers connected. In general, the 100 volts difference of potential would tend to cause a circulating current through the local circuit composed of the two groups of transformers, two lines, step up transformers and bus-bars. It seems probable that the impedance of this local circuit would be sufficient to prevent a large enough current to harm the transformer. The magnitude of the circulating current and its phase relation

to the load current would be determined by the characteristics of the local circuit and it might add to the load current in such a way that the load on the 6000 k.v.a. bank would not be much, if any, diminished by connecting the 600 k.v.a. bank in parallel with it. J.B.G.

1670—ENAMEL INSULATION—Has enamel ever been used for insulating the ribbon wound (edgewise) conductors used so extensively on the larger synchronous motor fields now on the market? We have a ten pole, 625 k.v.a. synchronous condenser with ribbon wound field coils on which the field insulation has about broken down by overheating, and we have been considering trying to enamel the conductor, but would like your advice as to whether it is practical. The exciter voltage is 125 volts. Kindly state what the specific gravity of the enamel should be to give the right coating, and how long it should be baked. Also the best way to remove the present insulation. F.W. (TENN.)

If your question refers to the type of enamel used in making enamel wire we do not feel it would be advisable for you to attempt to enamel ribbon-wound field coils. If however, you refer to a material such as black asphaltum enamel this would be a comparatively simple matter to apply, although of questionable value for your application, as it will become brittle due to the heat and will flake off. It should be applied by dipping, if possible, using a specific gravity of about 0.850 at 25 degrees C. and baking at 100 to 110 degrees C. for eight to ten hours or until hard. To remove the present insulation, immerse in a half and half mixture of benzol and alcohol, or alcohol itself will do if the benzol is not available, but it will act more slowly. W.F.E.

1671—GENERATOR DISCHARGE RESISTANCE—How can I figure the discharge resistance of a generator field? P.J. (OHIO)

Assuming that the induction effect of a generator field tends to maintain the current flow in the discharge resistor at the same value as at the instant before the switch was opened the problem is to design the resistor of such ohmic value that the voltage drop due to that current is kept at a safe value. This depends on the design of the field. Probably half of the standard test voltage would be safe. Thus for a 250 volt field tested at 1500 volts the drop through the discharge resistance should not exceed 750 volts. For a 600 volt field tested at 2500 volts a 1200 volt drop would be allowable. For fields of ordinary design it can be shown that the energy of discharge is small compared with the energy drawn from the line through the discharge resistor at the instant before the field is opened, and the capacity of the discharge resistor is therefore made sufficient to absorb energy from the line for several seconds, to provide for cases where the switch might be opened very slowly. H.C.N.

1672—TESTING ARMATURE WINDINGS—Can you give me a method of locating grounded, short-circuited, or open coils in wave, or two circuit armature windings? Is there a way of doing this with any degree of accuracy with a buzzer and telephone receiver? Can either of these defects, or coil ends, be located without unsoldering the leads from the commutator? What would be about the lowest safe limit for insulation resistance in ohms, of 220 volt crane armatures? F.W.E. (PA.)

A very simple method of testing for a ground is by a lighting out line. If it is a dead ground that cannot be located on the surface of the armature, it may be necessary to take up all leads out of the commutator neck to locate which coil is grounded. In testing for a short-circuited or an open coil, a telephone outfit, as shown in Fig. (a) gives very good results. Terminals *A* from the buzzer and battery circuit are spaced to span two adjacent commutator bars and terminals *B* from telephone receiver are mounted directly above terminals *A* so that when terminals *A* are pressed on the commutator bars, terminals *B* make contact with terminals *A*. A loud sound in the receiver indicates an open circuit. No sound indicates a short-

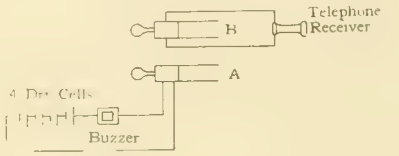

FIG. 1672(a)

circuit. A medium sound indicates that the coil is O. K. It is not necessary to unsolder the leads at the commutator until you have located the defective coils by test. Then look for the trouble in the coils soldered to the commutator bars under test and also on the two bars diametrically opposite. (180 degrees around surface of commutator). For 220 volt armatures, it is advisable to keep the insulation resistance to ground at a value of 50 000 ohms or above. J.S.D.

1673—After an induction motor has been re-connected from 3000 volts to 400 volts by changing from single Y-connection to 4-parallel delta is the horse-power of the motor materially increased due to the excess of active iron? And have the efficiency, power-factor, and other characteristics been changed and in what measure? A.U. (MEX.)

According to a table published in the JOURNAL for Feb. 1916, p. 88, changing an induction motor winding from series star three phase to four parallel delta three phase changes the voltage of the motor to 15 percent of the original voltage, so that this change would make a 3000 volt motor suitable for 450 volts. When operated on 400 volts it would be approximately ten percent below normal. The characteristics of a typical induction motor on ten percent below normal voltage are given in an article by Mr. L. W. Smith in the JOURNAL for March 1917, p. 105. According to the curves given in Fig. 1 of this article a motor operating on 90 percent normal voltage will have 80 percent normal starting torque and pull-out torque, 95 percent normal core loss, 88 percent normal magnetizing current and something over 115 percent normal copper loss and percent slip. These figures are only typical and the exact figures are dependent entirely on how liberally the motor is designed. C.R.R.

1674—APPARATUS FOR TESTING ALTERNATING-CURRENT MOTORS—What apparatus can be used in making a running test of three-phase alternating-current motors, varying in horse-power from one to 100, also differing in voltage from 110 to 440, that would be feasible and economical? I am using a small generator set with a transformer but find it not practical in starting a motor over 25 horse-power. J.R.S. (CONN.)

If three-phase power of the desired frequency is obtainable in sufficient quantities that the switching on of motors is not objectionable, the most economical testing equipment is a three-phase transformer, suitably wound and connected to a switchboard, so that changes from 440 volts to the lower desired voltages may be quickly made. Should a three-phase or three single-phase transformers not be available and only approximate no-load losses be desired, two single-phase transformers connected in open delta should prove satisfactory. For "runing light" readings, transformers totalling 50 k. v. a. should be sufficient for 100 horse-power motors. The smaller sizes may be started on full voltage and the larger sizes on half voltage. Should only direct-current be available, a 50 kw motor-generator set with a suitable transformer should be sufficient, providing the motor will stand a heavy momentary over-load, while the motor on test is being started. Lowering the frequency as much as possible while pulling in the alternating-current motor will allow a much larger machine to be started with the same equipment. Should full-load running tests be desired, the capacity of the above equipment should be doubled. E.M.MCC.

1675—ADJUSTABLE SPEED MOTOR—At what point is a variable speed, 220 volt, direct-current motor the more efficient, at a predetermined speed for which the controller is set, or with the motor run under full field and all armature resistance out of the circuit? Is the horse-power and commutation or both impaired with an increase in speed? D.F.Z (KANS.)

The most efficient point of operation of any motor is reached when the total variable losses equal the total constant losses. The variable losses include loss of armature winding; commutating-pole field coils, series field coils and the loss in brush contact. The constant losses include bearing friction, brush friction, windage, loss in shunt field and rheostat, and iron loss. In adjustable speed machines, the low speed usually has higher efficiency than the high speed point of operation. This is due to the rapid increase in windage and the brush and bearing friction as the speed is increased. The loss in the shunt field and rheostat is less at high speed than at low speed, but this gain is more than offset by increase in the other losses mentioned. The horse-power of an adjustable-speed motor should be unchanged throughout the speed range. Commutation troubles may be expected to increase with increase of speed. E.M.C.

1676—RAIL BONDING—(a) Please inform me why in street railway interurban service, etc., they bond both traffic rails for the return circuit? (b) could only one of the rails be used

for a short distance of say 25 or 30 feet for the return? (c) Can a relay be made that will not have over 100 microhms resistance and yet not close the circuit by the vibrations and shock of a car? (d) What is the resistance of the average mile of track considering both rails? R.E.M. (MICH.)

(a) Both rails should be bonded for two reasons:—a—It reduces resistance and consequent losses. b—If one bond breaks, the return path is not entirely interrupted. Tracks are cross-bonded frequently at approximately 1 000 feet spacing. (b) Yes. The bonds must be of proper size. (c) Relays for use on rolling stock should not be delicate. They are reliable only when their minimum contact pressure can be measured in ounces. The resistance of coils has not much bearing on the operation, as it is the ampere-turns and resultant flux which determine the contact pressure. (d) The resistance of the track varies with the size and shape of rail, size of bonds and method of applying bonds. We recommend consulting Richey's "Electric Railway Handbook," p. 695, for this data. A.H.C.

1677—Switching Grounded Circuit—Our system consists of star wound generators with neutral brought out and grounded generating three-phase, 60 cycle, 6600 volt current and connected through delta-delta transformers to our 66 kv lines, which are not grounded. I have noticed several times when one wire of one of these 66 kv lines becomes grounded, when the line switch is opened, there will be a heavy bump like a short-circuit, as the switch opens. If the switch is closed again the ground still remains and the heavy bump may or may not repeat itself when the switch is again opened. I believe there is an immense strain set up when opening a switch connecting one of these lines which has become grounded, as a short time since we opened a line switch which tied a good line to the grounded line and when the switch opened, a 66 kv current transformer on the good line broke down to ground. This current transformer must have been on the same phase as the grounded wire as the two lines were again tied together by closing the same switch and there was no short-circuit. Will you explain what causes this heavy bump? What would be the result if instead of opening the 66 kv switch the 6600 volt switch on the transformers was opened? Would there be danger of the strain breaking down the winding of the transformers? Why is not this bump heard every time the switch is opened? Is it because of the point on the cycle the opening takes place? The above grounds on 66 kv lines were caused by breaking down of insulators and I am unable to say how good a ground was made. However, the aluminum cell arresters spilled over very badly on the system at the time. L.A.F. (MASS.)

It is probable that the bump, sounding like a short-circuit, has occurred when the circuit breaker opens, not because there was any connection between the opening of the breaker and this bump, but because the latter has been the result of an actual short-circuit occurring at the time of opening and started by an arcing ground on one wire, either by the arc striking over to another wire of the circuit, or by the surge or oscillation of potential causing a breakdown of the series transformer. Opening the circuit breaker on the 6600 volt side instead of the 66 000 volt side of the transformer would not change the situation. The surges and oscillations on the circuit which cause such conditions can be practically eliminated by the grounding of the neutral point on the high tension side. In case of delta-connected transformers, it would be necessary to establish a neutral point by using star-connected transformers. While there are certain disadvantages in the use of the grounded neutral, these are very small and are far outweighed by the protection afforded against oscillating conditions set up by arcing grounds, to which the ungrounded system is liable. A.W.C.

CORRECTION

The diagram Fig. 1650(a) on p. 430 of the Journal for October 1918, is incorrect. It should be as follows:

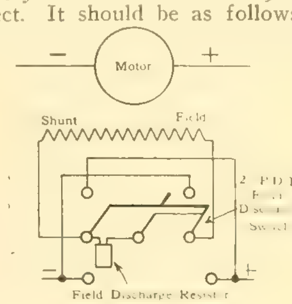

FIG. 1650(a)

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

NOVEMBER 1918

Protection of Motor Bearings from Dust

Dust, sand, etc., when mixed with oil, have a grinding action on bearings, wearing away the bearing linings as well as the shaft or axle. As a result, various means have been taken to make these bearings dust proof and thus extend their life in service.

OIL BOXES

It is necessary to keep dirt, water, etc., out of the oil so that it will not be drawn into the bearing surface with the oil. This is done by having a tight cover over the oil and waste pockets, held in place by a spring. This cover should be lined with felt and should have a deep lip to prevent wheel wash, etc., from splashing in.

ARMATURE BEARINGS

The outer end of the commutator end armature bearing is ordinarily protected by a dust cap over the end of the shaft. This cap is made of sheet steel or malleable iron and is fastened to the housing or the bearing by bolts or screws, completely enclosing this end of the bearing. This dust cap should always be kept in place as the position of the bearing with respect to the wheel flange is such as to permit the dirt, sand and wheel wash from the wheel flange to be thrown directly on this part of the motor.

The outer end of the pinion end bearing usually extends into the gear case and needs no further protection. The gear case fits over the armature bearing or an extension of the housing with a sufficiently close fit to keep the lubricant in the gear case and tends to keep dirt out of the bearing at this point. There is very little possibility of dirt, etc., getting into the armature bearings from the inside of the motor as the oil throwers on the shaft and oil catchers on the housings, act as guards and give ample protection against the entrance of dirt.

AXLE BEARINGS, PINION END

The gear case acts as a dust protection for the outer end of the pinion and axle bearing in much the same manner as for the armature bearing, as the usual practice is for the gear case to fit over the flange of the bearing. Until recent years, this was the only dust protection provided for the axle bearings, but now it is usual practice to supply axle shields enclosing the axle between axle bearings and axle bearing dust guards to protect the commutator and axle bearing flange from dust.

AXLE BEARING DUST GUARD, COMMUTATOR END

The object of this dust guard is to protect the bearing surface of the axle bearing flange where it bears on the wheel hub or axle collar. This takes several forms. It may be cast solid with the frame and axle cap; it may be made part of the axle collar extending out over the axle bearing flange, or it may be bolted to the axle bearing flange and extend out over the axle collar flange or machined wheel hub. This last is the most usual form and generally has a felt liner which rubs on the axle collar flange or the wheel hub to provide efficient protection against the entrance of dirt at this point. It is made of malleable iron or pressed steel.

AXLE SHIELDS, OVER AXLE BETWEEN BEARINGS

Axle shields are of a number of types, depending on size of motor and shape of frame at the axle. A simple type for small motors consists of a cylindrical sheet steel shield. This is split longitudinally to allow it to be placed over axle and extends under the axle caps from axle bearing to axle bearing, being held by the axle caps. It is usually provided with windows for inspection of axle bearings without removal of axle caps or shield.

Where there is not sufficient clearance between the frame and axle to permit use of a cylindrical shield, a semi-cylindrical shield is used. This fits against the frame and is held by the axle caps the same as in the case of the cylindrical shield. In order to afford proper protection, this shield should fit against a machined surface on the frame and there should be a ledge from the frame, extending out over the joint.

In the case of the larger motors, this method of holding the axle shield is not satisfactory, as the axle caps are heavy and when installing a motor on the truck, it would be very difficult to hold the shield and axle cap at the same time while tightening bolts, as would be necessary with this construction. Therefore a semicylindrical shield is used, held in place by straps bolted to the frame by tap bolts. In this case it is not necessary to provide windows, as it is a very simple matter to remove the axle shield to inspect the axle bearings.

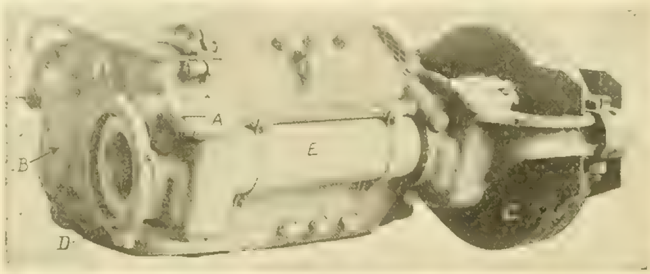

FIG. 1—TYPICAL RAILWAY MOTOR EQUIPPED WITH PROTECTIVE IMPROVEMENTS

A—Dust-proof oil box cover; *B*—Commutator end armature bearing dust caps; *C*—Dust-proof gear case; *D*—Commutator end axle bearing dust cap; and *E*—Axle shields.

APPLICATION OF OLD MOTORS

Where motors are in service which are not equipped with commutator end dust guards and axle shields, it is usually possible to apply these parts with little expense and considerable resultant saving. The application of dust guards will depend on the relative diameters of axle bearing flange and the axle collar flange or wheel hub, and on whether there are parts of frame or axle caps extending over the axle bearing flange. It will usually be possible to apply an axle shield of one of the types described above or some modification, but it may be difficult to get a tight fit of the shield against an unfinished frame casting and the protection afforded will always depend on the tightness of the joints.

SOME RESULTS

The application of dust guards and axle shields, where possible, will more than pay for itself in increased life of bearings. There have been reports of railway companies which have increased the life of the bearings three to five times and it will nearly always be possible to double their life when efficient dust protection is provided.

The Electric Journal

Vol. XV | December, 1918 | No. 12

The Electrically-Operated Liberty Mill

Prior to the cessation of hostilities in Europe, there were many engineering developments which, while their discussion would have been very interesting to Journal readers, did not for obvious reasons appear in these pages. The reasons are now largely disappearing, and it is planned to present a number of articles on such subjects.

In the present issue appears an article by Messrs. Menk and Hunt describing an engineering achievement of no mean magnitude—the design and construction of the 110 inch Liberty Plate Mill by the Homestead works of the Carnegie Steel Company, in the extremely short period of six months, in order to get into production in time to assist the Emergency Fleet Corporation. This mill was built by men who were already engaged in the operation of an immense steel plant working to capacity on rush war work. Labor, in the ordinary sense of the word, was not available and recourse was made to various mechanical methods which, along with volunteer labor by officials, clerks, mechanics and other steel mill workers, saved the day.

In addition to the actual mill construction, it was necessary to remove 70 000 tons of steel and other material from the site, to remove 40 miles of railroad track, to construct a five foot sewer, 1000 feet long at a depth of 18 feet, to build an addition to the power house and install additional apparatus, to erect a transmission line, including a 1000 feet span across the Monongahela River. The steel mill buildings themselves were erected in 49 days and numerous other records were made in the production and assembly of the mill machinery by the various manufacturers, who were already loaded with priority work.

This is the first plate mill of the Carnegie Steel Company to be all-electrically driven and its satisfactory operation and rate of output will doubtless mean that all future installations will be all-electric likewise.

A. H. McIntire

Distribution Transformer Performance Characteristics

For many years, but particularly since the advent of silicon steel with its remarkable effect on transformer performance, the extreme importance of using highly efficient distribution transformers in order to keep down operating costs, has been fully recognized by the central stations of this country. The demand for high efficiency has resulted naturally from three conditions. First—the average size of the distribution transformers installed has been small, probably averaging not over 7.5 k.v.a. per unit, considering only those sizes up to and including 50 k.v.a. capacity. Second—the load factor has usually been poor, so that under average operating conditions the equivalent load has been in general not greater than four hours full load per day. Third—the diversity factor of the load supplied has usually permitted the installation of power and substation transformers of a rating possibly less than one-third or one-fourth of the total k.v.a. rating of the distribution transformers connected to the system.

The conditions cited above for the distribution transformers are all adverse to a high operating efficiency as compared with the power or substation units. Small machines are inherently less efficient than large, while the combination of a poor load factor with a large number of units installed makes the comparison still more unfavorable. The demand, therefore, has been for a distribution transformer with an efficiency comparable with that of its larger brother, and with a ratio of losses designed to give the best operation under conditions of a poor load factor.

The fact that the desired result has been achieved without an excessive cost per k.v.a. is a tribute to the splendid engineering embodied in the design of a modern distribution transformer. Refinements enter into its construction that are not given as much weight when larger capacities are considered. Materials are worked at lower densities; the shape of copper and magnetic circuits closely approximates the ideal transformer; the magnetic circuit is built up of L punchings; and the expedient of increasing the area of cross-section of the magnetic circuit outside the coils is made use of with the result that a remarkably efficient, small capacity transformer has been obtained.

The simple fact is, however, that all designs are in the nature of a compromise or balance between different characteristics; that is to say, there are always characteristics in mutual conflict, so that a design has been likened to a ball of putty, which when squeezed at one place immediately changes its shape at some other place. The iron and copper losses of a transformer are related to each other in this way, inasmuch as, while they can be varied with respect to each other in a given design, their product is approximately constant, so that it is impossible to decrease one without a proportionate increase in the other.

In view of the possible variation in the ratio of the iron and copper losses in the same design, an interesting question arises as to the best ratio of these losses under the operating conditions met with on the average distribution system. The answer to this question is supplied in Mr. Reed's article in this issue of the Journal, in which he shows that the ratio of copper loss to iron loss should not exceed a figure of 2.5 to 3 for the lowest operating costs. Superficially a higher ratio of copper to iron would appear desirable on account of the poor load factor encountered, but this conclusion would ignore entirely the fixed charges in the cost of supplying power.

The value of regulation is not included by Mr. Reed in his calculations. It is important, however, to keep in mind the fact which Mr. Reed points out, namely, that poor regulation directly affects the registration of energy at the consumer's meter. Regulation, therefore, should properly be evaluated at the selling price rather than at the cost of the electric energy, and it is from this fact that its importance arises. Inasmuch as regulation is directly related to copper loss, its inclusion in the problem would have the effect of still further reducing the ratio of copper to iron loss, for the condition of lowest operating expense.

A. C. FARMER

Periodic Meter Testing Could some modern wizard, through a miracle of engineering, produce a steam turbine and an electric generator of 100 percent efficiency, he would be welcomed with open arms by central station operators. Yet such a revolutionary advance in the art would mean less to the industry than would the elimination of a possible one percent average slowness of the watthour meters on their systems. Though cheap and inconspicuous, the fountain head of gross income is not to be treated slightingly.

The modern induction watthour meter is a remarkably accurate measuring device and, without attention, will retain its accuracy for long periods of time, being but little surpassed in accuracy by a jeweled timepiece. Through a gradual process of development the effects of internal friction, creepage, temperature variations, voltage and frequency fluctations, power-factor changes and the other ills to which meters are inherently liable have been reduced to within very narrow limits. Yet even an expensive watch needs periodic cleaning and adjusting, and a watthour meter needs it no less.

During the war, in the spirit of conservation, this periodic testing and inspection has been cut down to a minimum in many if not most cities. But it should be renewed as promptly as conditions permit, for, while certain combinations of circumstances will cause a meter to run fast, undoubtedly the great majority of inacurate meters are slow rather than fast.

Thrift and economy are going to be the outstanding characteristics of the reconstruction period following the war—for several reasons. One of these is that we have gotten into that way of thinking during the war. Another reason of vital importance to public utilities is that operating expenses are high, and coal and new apparatus are expensive. The central stations must continue to think in terms of thrift and economy. Systematic meter testing, especially after a period of neglect, is distinctly worth while. And even where its expense may exceed the direct financial returns, the increased confidence of the public in the accuracy of their bills is no small asset. Contrary to the facts, there seems to be a general feeling on the part of the public that almost any meter is fully qualified for entry in a long distance, high-speed, endurance contest, a feeling which can only be removed by a consistent policy of education on the part of the central station.

CHAS. R. RIKER

Safety First— Always an Essential Whatever may have been the motives that prompted manufacturers and public service companies to aid in safety first work—whether humanitarian or a realization that it had a sound economic basis, or both, safety first work demands still further attention now. When the safety first campaigns were first started, labor of the desired amount and average quality was obtainable. At present help must frequently be accepted from those not qualified by experience or education in the fundamentals of electrical work, and there will doubtless be much shifting around in the next few months.

Operating men whether engaged in the generation or utilization of power, now owe a duty to their employing corporation and fellow workers to make sure that all practicable provisions are made to ensure the greatest safety to inexperienced workers and the greatest protection against the interruption of power supply. Assuming a continuous supply of power, there is still its safe distribution and utilization, and here especially is where inexperienced help must be given special protection to make sure that there will be no interruption either of the service of employees or of power. In this connection the Supreme Court of Pennsylvania in a recent decision* has stated quite clearly the legal requirements and with these all operating officials should be fully acquainted. This decision states that "electric companies are bound to use the highest degree of care practicable to avoid injury to every one who may lawfully be in proximity to their wires, including employees," that it is their duty "to know what safety appliances are suitable and in common and ordinary use", for protective purposes. "Furthermore, when a particular safety appliance has come into general use, it is the duty of an electric company to furnish its employees with the protection which that device affords." Referring particularly to outside line construction work, it is cited, for instance, that it is customary for employers to furnish linemen with rubber gloves, shoes and "what are termed 'piggies' (hollow rubber cylinders about three feet long, which after being clasped about live wires render the latter innocuous to those who may touch or come in contact with them)" and it is brought out in this decision that employers may be considered guilty of negligence by failure to furnish their employees with such usual and ordinary safe guards from injury due to electrical causes.

Aside from the legal point of view, it is high time that electricity be considered universally by the general public as a useful servant rather than as a highly mysterious and dangerous agency, and suitable safeguards will go a long way toward the elimination of any but useful demonstrations of the power of electricity.

A. H. McINTIRE

*Donelly vs. Lehigh Nav. Electric Co.

The Liberty Mill of the Carnegie Steel Company

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THE 110 inch plate mill, better known as the "Liberty Mill", is the first completely electrically-driven plate mill to be placed in operation by the Carnegie Steel Company. It is an entirely complete plate mill unit built and operated by the Homestead Works of the Company and located on the south bank of the Monongahela River, west of the plant proper. While built primarily as an emergency mill to roll plates for the Emergency Fleet Corporation, it has been constructed in the most substantial manner for continued operation after the war.

At the time orders were received from Corporation headquarters to build this mill, absolutely nothing had been done in the way of preliminary estimates or designs, and no parts of existing mills could be utilized in its construction. But in the short period of six months the mill, covering a total area of 215 000 square feet, had been erected and placed in operation. Not only did this period cover actual designing and construction of the mill, and practically all of the equipment in the mill, but also the removal of 70 000 tons of scrap from the site before the actual survey could be made. The motor driving the main rolls and many of the smaller motors were also entirely constructed in this time.

In the Liberty Mill not only are the main rolls and tables motor driven, but also all auxiliaries, as pressure pumps, compressors, etc. Power for the operation of this mill is obtained from the gas engine-driven power plant at the Carrie Furnaces, the blast furnace connected with the Homestead plant and located on the north bank of the Monongahela River about two miles farther up. At this station power is generated at 6600 volts, three phase, 25 cycles. One additional generating unit of 3500 k.v.a. capacity had to be added to enable the station to handle the increased load, making the total capacity of the station 19 600 k.v.a. It was also necessary to erect a transmission line from this station to the mill. This line consists of two three-phase circuits, either one of which is of sufficient capacity to carry the load of the mill, and is made up of 500 000 circ. mil copper 11 700 feet in length. This length also includes the river span of 1007 feet which is of 795 000 circ. mil aluminum cable, reinforced with a stranded steel core. This river span is carried on steel towers, the tower on the south bank being shown in Fig. 1. This is a dead end tower and is located back from the bank on the shore side of the main yard and the Union Railroad tracks, the lines being brought down the face of the tower and back across the tracks to a 50 foot pole line extending down the river bank to the mill.

All crane, charging machine and table motors are mill type direct-current motors, obtaining current at 230 volts from a motor-generator substation located in the axle department of the works near the Liberty Mill. All shears, compressors, and pumps are driven by alternating-current motors supplied at 240 volts from a step-down transformer substation located at the mill.

LAYOUT OF BUILDINGS AND EQUIPMENT

The group of buildings which form the mill, Fig. 2, are all joined together. On entering the mill one comes first to the slab storage building. This building is served by two 15 ton, 66 foot span traveling cranes, whose duty is to unload the cold slabs shipped into the mill, and also to deliver slabs to the transfer tables leading into the furnace building, which is parallel to the slab building. These and all other cranes, charging machines, and practically all of the equipment, as before stated were designed and built by the Homestead Plant.

FIG. 1 DEAD END TOWER OPPOSITE POWER HOUSE
Tower stands 134 feet high being 28 by 30 feet at the base. The cross arm members are 56 feet, 66 feet, and 56 feet long respectively. Provision has been made for four three-phase circuits, three of which are now in place.

These slab yard cranes are each equipped with a 75 hp motor on the hoist, a 55 hp on the bridge, and a 15 hp on the trolley, manual control being used for all motions.

The transfer table for transferring slabs from the storage building to the furnace building consists of two units, each unit of 18 rollers driven by a 37.5 hp motor, which is operated by series accelerating magnetic control. This controller, as are all magnetic controllers, is mounted in a steel shelter, Fig. 3, while the master switches are located near the table. This table extends into the furnace building in which are located eight regenerative furnaces.

Slabs are charged from the transfer tables into the furnaces and drawn from the furnaces for delivery to the mill by two 15 ton overhead charging machines of 45 foot span, shown in Fig. 4. The bridge of each is driven by two 37.5 hp motors, each motor being controlled by a separate magnetic controller, but both controllers operated by one master switch. On all other

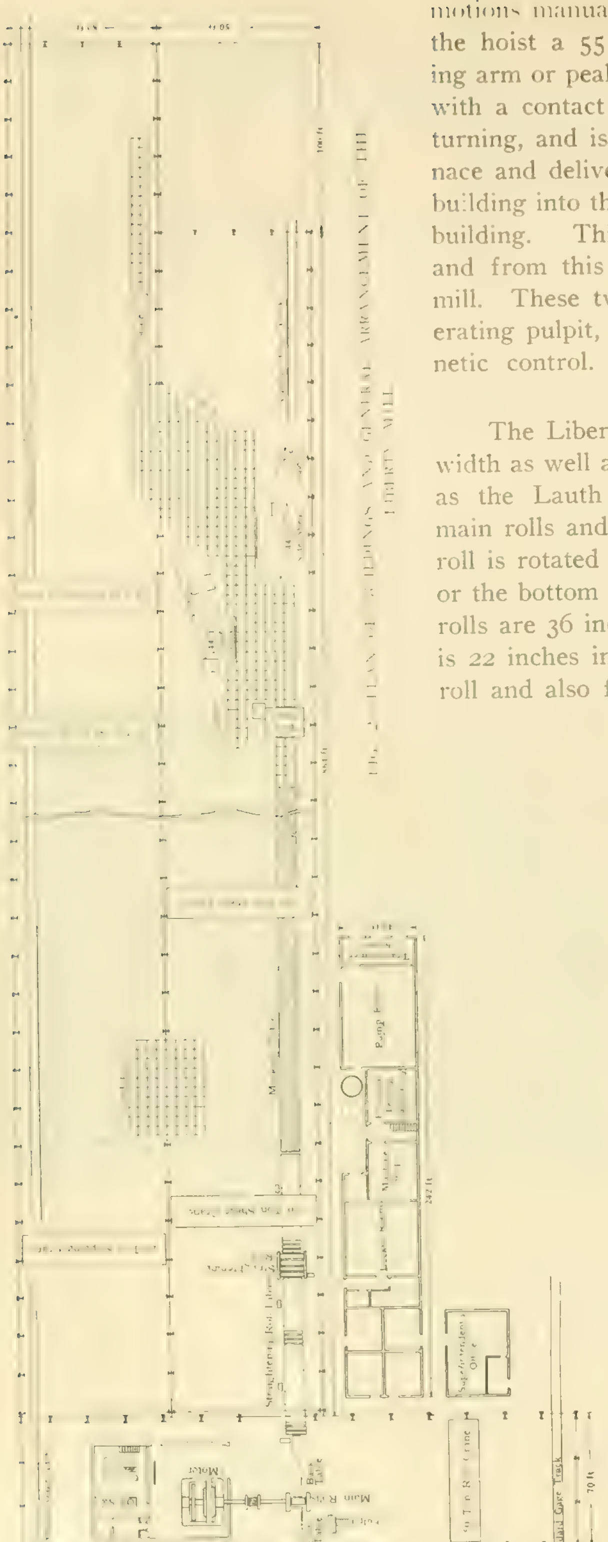


FIG. 2—PLAN OF BUILDINGS AND GENERAL ARRANGEMENT OF THE LIBERTY MILL

motions manual control is used. The trolley is driven by a 37.5 hp motor, the hoist a 55 hp, and the screw for operating the clamp on the charging arm or peal is driven by a 15 hp motor. The turn-around is equipped with a contact column for all connections, thereby permitting continuous turning, and is driven by a 15 hp motor. Slabs are drawn from the furnace and delivered to the delivery table, extending from the furnace building into the roll or mill building, which is parallel to the furnace building. This table consists of 26 rollers driven by a 37.5 hp motor and from this table the slabs run to the front table and thence to the mill. These two tables and the back table are all controlled from an operating pulpit, by means of master switches and series accelerating magnetic control. These two mill tables are each driven by a 100 hp motor.

MAIN ROLLS AND DRIVE

The Liberty Mill is a shear plate mill, that is, all plates are sheared to width as well as length, there being no side rolls. It is what is known as the Lauth type mill in which the top and bottom rolls are the main rolls and are driven in the same direction, while the smaller middle roll is rotated by friction as it is successively forced against either the top or the bottom roll by the rolling pressure. In this case the top and bottom rolls are 36 inches in diameter and 110 inches long, while the middle roll is 22 inches in diameter. Hydraulic pressure is used to move this middle roll and also for tilting the front and back tables.

FIG. 3—TYPICAL METHOD OF MOUNTING MAGNETIC CONTROL APPARATUS IN STEEL SHELTER BETWEEN MAIN BUILDING COLUMNS

The main rolls are driven by a 4000 hp, three-phase, 6600 volt motor running at 83.3 r.p.m. This is connected to the rolls by means of cast herringbone pinions, the motor pinion having 11 teeth to 17 on the roll pinion. This gives a peripheral speed on the roll of 513 feet per minute. The motor is enclosed in a separate brick building inside the main building and under the 50 ton, 66 foot span roll crane. The entire roof of this building, Fig. 5, may be removed and also the rolling steel door may be lifted away, giving access to all parts of the motor room with the crane.

The 4000 hp main motor is of the standard two-bearing, wound rotor type of induction motor and is shown in Fig. 6. The flywheel is mounted directly on the rotor shaft between the main bearings. This flywheel is 19 feet in diameter and weighs 55 tons, and the total rotating element weighs 118.6 tons. Some idea of the speed made during construction may be had by the fact that just two weeks after the first part of the motor or control apparatus was received on the site, the motor was turning over the rolls, complete in every detail. This first part received was the bedplate and

approximately one week later the stator. Three days before the mill started, the rotor and all control equipment arrived. The same record was maintained in all construction.

The room in which the motor is located is 50 feet by 55 feet and also contains the switchboard, Fig 7. The first panel on the left contains the control buttons

FIG. 4—15 TON CHARGING MACHINE, FURNACE BUILDING

for the motor-operated oil circuit breakers in each circuit from the power house. The motor primary panels are next, containing the indicating and graphic meters. The remaining panels contain the contactors and relays for cutting out secondary resistance for accelerating, and also the notch-back relay for opening the last contactor. The motor runs with resistance normally connected to give five percent slip, and when the contactor is opened by action of the notch-back relay connected

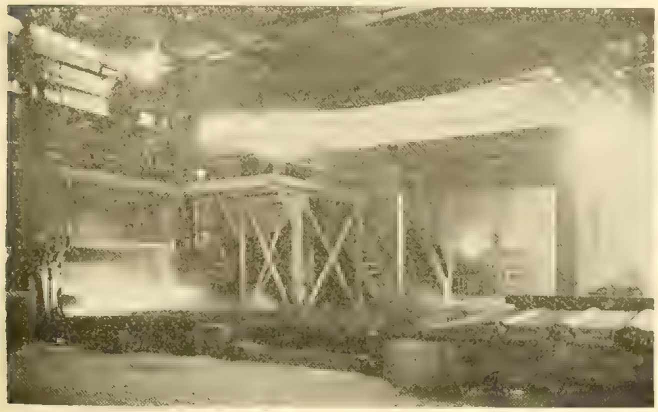


FIG. 5—LOOKING ACROSS REAR ROLL TABLE, SHOWING MOTOR ROOM
The rolling steel door at main entrance may be lifted away, as may also any portion of the roof. This view also shows the method of installing the motor and belt drive for the screw down.

to the transformers on the motor primary, an additional four percent is added, thereby permitting the flywheel to give up energy.

In the same building and back of the room containing the motor is a room 22 by 50 feet, Fig. 8, into which the main power lines are brought in lead-covered cables and in which are located the lightning arresters, oil circuit breaker cells and secondary resistance. The oil circuit breakers for the incoming lines are the first two sets of cells on the right, the barrier doors of one being removed to show the construction of the concrete cells. The next set of cells contain the circuit breaker on the motor primary and the last two on the left, the reversing circuit breakers for plugging the motor. The cell between the primary circuit breaker and the reversing circuit breakers contains the step-down transformer for supplying 220 volts for operating the contactors on the secondary control. In the foreground may be seen the banks of grids forming the motor secondary resistance. Fig. 9 shows the lightning arresters on the incoming lines. These are located back of the concrete cell structure shown in Fig. 8. All instrument transformers on the 6600 volt lines are contained in the concrete cell structure. The primary leads for the motor are lead covered cable and are brought from the oil circuit breakers down into the basement where they pass

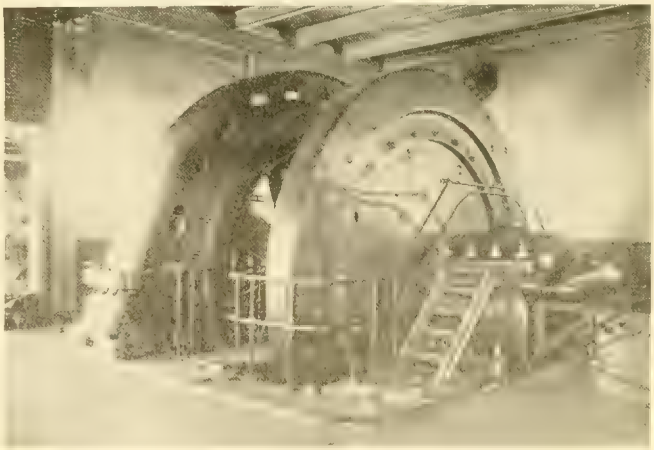


FIG. 6—4000 HORSE POWER MAIN MILL MOTOR AND FLYWHEEL

through current transformers operating the notch-back relay, and thence in conduit through the motor foundation to the motor.

A better view of the secondary resistance grids is shown in Fig. 10, which shows the copper bus connections between banks and the bus connections from the terminals. All connections from the grids to the contactors and slip rings on the motor are made with bus copper, which is run through openings in the floor at each terminal point to the basement. From this basement a tunnel leads to the pit under the motor, passing directly under the switchboard containing the secondary contactors. The connections to the contactors are brought up through openings in the floor back of this board. These bus-bars are all rigidly supported on insulators carried on pipe frame work, making all connections readily accessible. Fig. 11 shows the basement and tunnel mouth, also the bus-bars coming from the resistance above and into the tunnel. The bottom set of bars in the background is connected to the slip rings on the motor.

All floors are covered with red quarry tile and the building is equipped with a telephone room, toilet, and

work room. Also it is supplied with fresh air from a motor-driven blower delivering air under the motor and in the basement under the resistance. Suitable outlets are provided in all rooms.

Mention has been made of reversing switches on the motor primary. While this is a continuous running mill, these switches have been provided for plugging the motor to enable the operator to stop it quickly or to reverse its direction of rotation in case of emergency.

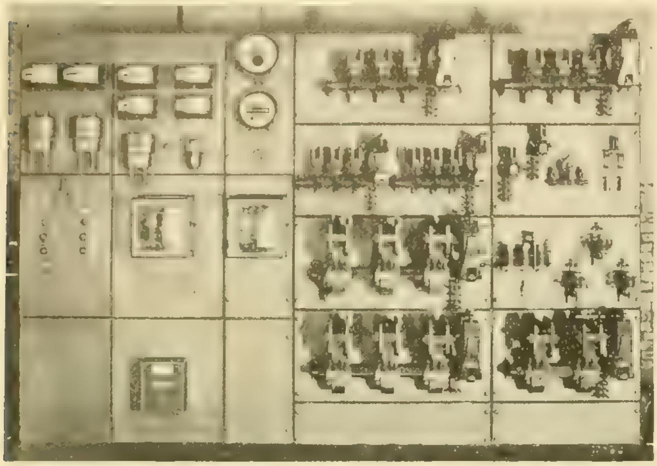


FIG. 7—VIEW OF SWITCHBOARD IN MOTOR ROOM
Showing control panel for incoming line switches and contactors for motor secondary control.

The friction and windage losses of the motor plus the friction load of the pinions and mill is 177 kw, yet without plugging, the motor does not come to rest for approximately 4 minutes, due to the flywheel effect of the rotating parts. The master switch for controlling the motor is located beside the roller's desk, giving him complete control of the mill. Several safety stops are arranged to be operated from the motor room, but the motor cannot be started from any place other than the master. In case the motor is stopped for any reason from within the motor room, the master must first be returned to the off position, before it can again be started. Pilot lights have been provided in plain sight of the roller, showing green for switches open, red during acceleration, and white when motor is up to full speed. A compressed air whistle is used for all signals and is operated by a solenoid valve from either the roller's desk, or the switch-board in the motor room. The control pulpit also contains the master switches for operating the approach table and the front and rear mill tables, also the lever-type hydraulic valves for raising and lowering the mill tables and operating the middle roll. These valves are small pilot valves that control the valves on the main pressure lines. The master switch for the screw-down motor control is also on the same pulpit. This screw down is operated by a 100 hp motor, controlled by series accelerating magnetic control and is belted to the main shaft driving the screws. On this and all table controls, plugging is used for quick stops. Two operators control this equipment, one operating the screw-down motor, the other taking care of the remaining motions. They are located at one side of the mill and opposite the front table.

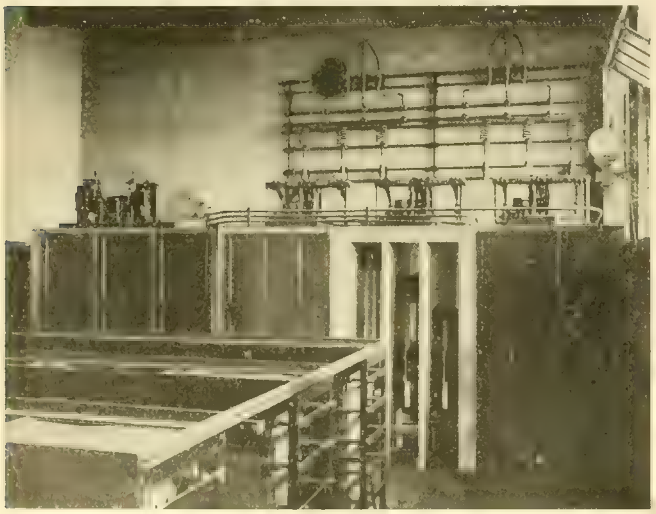


FIG. 8—GENERAL VIEW OF INCOMING LINES, DISCONNECTING SWITCHES, CHOKE COILS, CIRCUIT BRAKER CELLS AND MOTOR SECONDARY RESISTANCE

FIG. 9—INCOMING LINES AND LIGHTNING ARRESTERS

Roll changes are quickly made as the mill is of the open housing type in which the rolls are taken out endwise through the housing. This work is handled by the 50 ton roll crane, which is equipped with two 37.5 hp motors on the bridge, each motor operated by a separate magnetic controller, but controlled from one four-speed-point master switch. These controllers are equipped with shunt switches and series accelerating relays. The trolley is driven by a 37.5 hp motor and contains an auxiliary 15 ton hoist operated by a 55 hp motor, as well as the main hoist which is operated by a

FIG. 10—SECONDARY RESISTANCE GRIDS
Showing method of mounting and connecting.

75 hp motor. Dynamic braking is used on the main hoist and manual control on all motions except the bridge.

SHEAR BUILDING

The shear building, Fig. 12, extends at right angles to the mill building and the plates, on being finished,

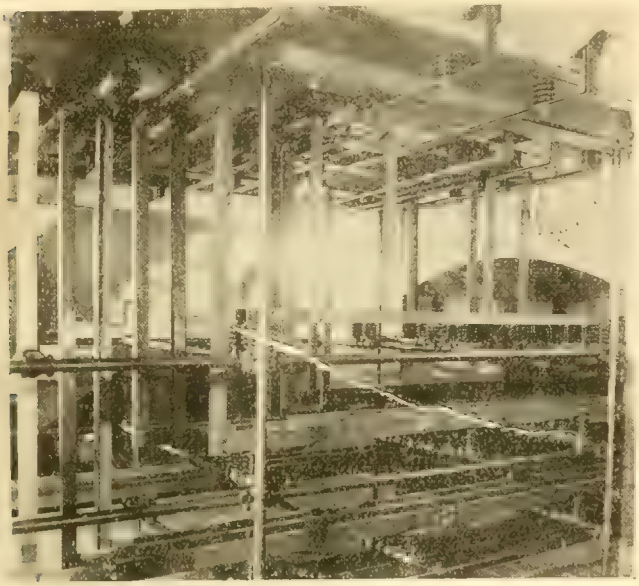


FIG. 11—BASEMENT UNDER SECONDARY RESISTANCE
Showing connections between resistance and contactors, and resistance and slip rings on motor.

are run off of the rear table onto an intermediate table extending into the shear building. This table carries the plates to the front straightening roll table and thence to the straightening rolls. These rolls consist of six lower rolls driven by a 75 hp compound-wound motor and five upper idler rolls which are adjusted by a

FIG. 12—SHEAR BUILDING SHOWING COLD ROLLS AND MARKING TABLES WITH SHEARS IN BACKGROUND

7.5 hp motor. These two tables, as well as the remaining tables between the straightening rolls and the shears are each driven by a 37.5 hp motor, and together with the straightening rolls are controlled from an operating pulpit located beside these rolls. All of these motors are operated by master switches and series accelerating magnetic controllers. The back straightening roll table carries the plate to the first of two marking tables, each of which is 163 feet long. The second marking table brings the plate to the 110 inch end shear and from there it may be pushed on the "casters" to either of the 144 inch side shears. Each of these three shears is driven by a 200 hp wound-rotor, 220 volt, three-phase

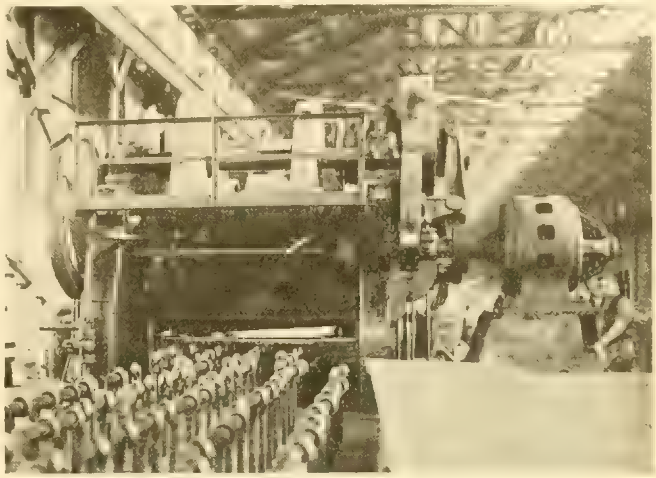


FIG. 13—MOTOR-DRIVEN END SHEARS

motor, controlled by a full magnetic starter operated from a pushbutton station. The end shear is shown in Fig. 13 and its control in Fig. 14. These motors are coupled to the shear through a flexible coupling to the driving pinion which is supported by its two independent bearings. Located back of each side shear is a scrap shear operated by a 40 hp squirrel cage motor controlled by a manually-operated starter. The casters used about the shears and from them to the shipping building are equipped with roller bearings and ball bearing thrust to reduce the labor to a minimum. This shear building is served by two 10

FIG. 14—CONTROL FOR MOTOR DRIVEN SHEARS

ton, 76 foot span cranes having a 55 hp motor on the bridge, a 55 hp motor on the trolley, and a 75 hp motor on the hoist; manual control being used on all motions.

SHIPPING BUILDING

The shipping building which lies parallel to the shear building is served by three 10 ton, 76 foot span cranes, the bridge of each being driven by a 55 hp motor and the trolley by a 15 hp. Each trolley contains

two independent hoists on overhanging drums, the cables hanging on either side of the bridge girders. These hoists may be operated singly, or as one unit, depending on the length of the plate to be handled. Each hoist is operated by a 37.5 hp motor which is controlled by magnetic control consisting of shunt switches and series relays. This control is arranged for dynamic braking and is operated by a four-speed-point master switch. These two hoist master switches are so located that they may both be moved as a single switch when the two hoists are operated as one unit. Manual control is used on the other motions. In order to be able to use part of the space in the shipping building for slab storage, if necessary, a transfer will be installed between the slab storage building and this shipping building. This will be motor operated and of the surface contact system. There is also to be installed a three

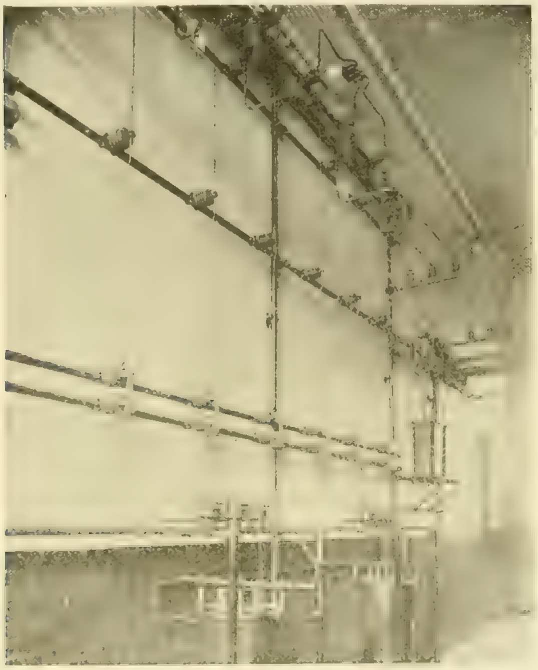


FIG. 15—INCOMING LINES AND LIGHTNING ARRESTERS IN TRANSFORMER SUB-STATION

ton monorail hoist for handling the cinder from the heating furnaces. This will run around the backs of all the furnaces in the furnace building.

SUBSTATION AND PUMP STATION

Parallel to the shear building is a long brick structure containing the headquarters for the electric foreman, millwright, labor foreman, etc.; the comfort station and locker room for employees; and the physical testing laboratory, consisting of a test room containing a 400 000 pound test machine, bending room, and a machine shop for machining the test pieces. Above these rooms are located the shipping and inspectors offices. Also in the same structure are the accumulator and return water tank connected with the hydraulic system. Also the transformer substation which consists of three 500 k.v.a., single-phase, air cooled transformers connected in delta. This station is supplied with power from the same two circuits as the main motor, the method of bringing in these lines being shown in Fig. 15, and the transformers which stand on the opposite side of the room from the lightning arresters being shown in Fig. 16. Open copper tubing, supported on insulators from pipe frame work is used for all prim-

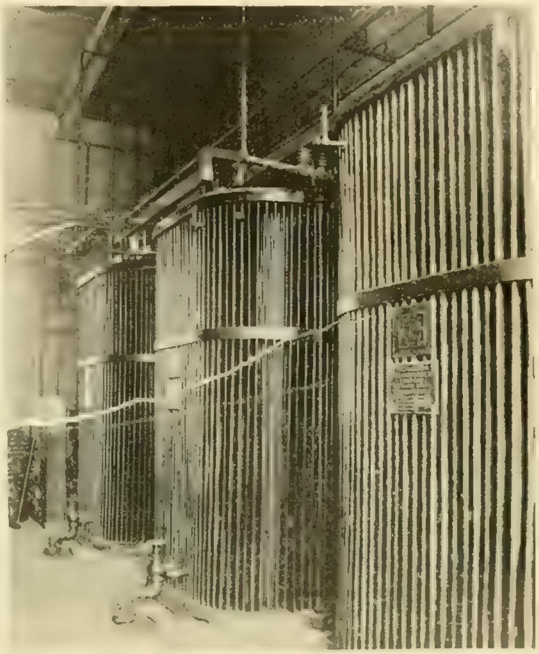


FIG. 16—6600 TO 240 VOLT TRANSFORMERS

For motors on shears, pumps and compressors. All open bus connections from transformer to switchboard.

ary connections, and open bar copper supported in a similar manner is used for all secondary connections. Each primary circuit is controlled by a remote electrically-operated oil circuit breaker located in barriers in line with the transformers.

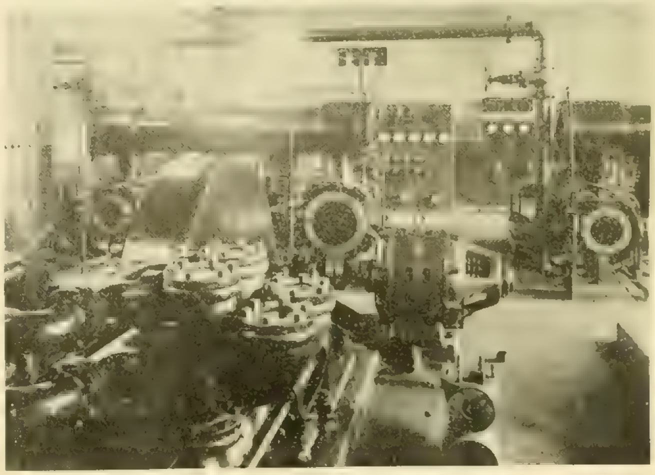


FIG. 17—GENERAL VIEW OF PUMP ROOM

Showing pressure pumps, air compressors and switchboard. Note open bus work coming from transformer room in rear of switchboard.

The secondary bus is carried through an opening in the wall to the switchboard located in the pump room which is adjacent to the transformer room. This

switchboard consists of two primary panels and two feeder panels, one being the shear circuit, the other for future use. Also a light panel, a tap being brought from the middle transformer, giving 120 volts for this purpose. Connected to the main bus are also the two synchronous motor panels for operating the two air compressors, and the two starting panels for the motor-driven pressure pumps. These compressors are each of 1500 cubic feet capacity and are driven by a 250 hp, 214 r.p.m. synchronous motor, the rotor of which is mounted directly on the crank shaft and excited from the general direct-current power system. Air pressure is maintained at 100 pounds. The pressure pumps are 5⅝ inch by 12 inch duplex pumps and are driven by a 100 hp wound-rotor motor through a flexible coupling and cut herringbone gears. The accumulator maintains a constant pressure of 550 pounds. Fig. 17 is a general view of this room.

OPERATING RESULTS

The Liberty Mill has now been successfully operated for over a year with no shut-downs and no serious delays. Plates are being rolled from slabs of an average weight of 4200 pounds, 4½ inches thick, and the average monthly output of finished plate is 19 000 tons. This average tonnage is made up of plates ranging from 1 11/16 inches to 3-16 inch thick and 96 inches wide. Fig. 18 shows a typical graphic curve of the power required while rolling a 5250 pound slab. The action of the flywheel in smoothing out the peak of the load during the heaviest reduction is clearly shown. Plates are being finished at an average total power consumption of 52 kw-hr. per ton. The mill is operating with an average practice of 75 percent, that is, the ratio of the tonnage charged to that finished. This includes all losses in scale in the furnace and during rolling and all scrap due to shearing.

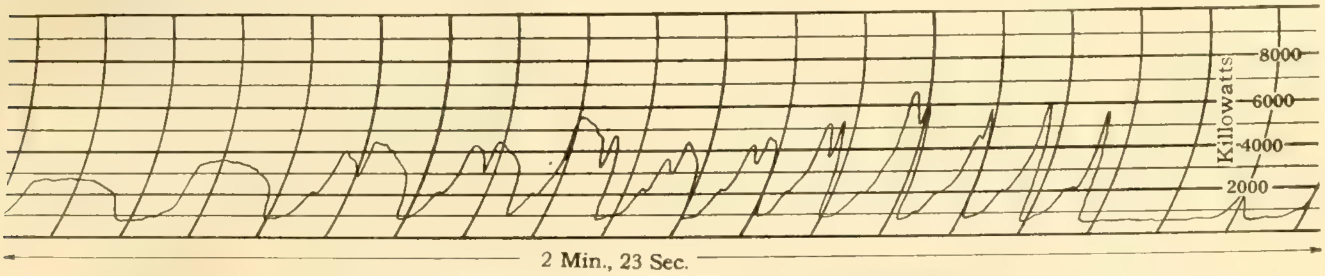


FIG. 18—TYPICAL WATTHOUR METER CHART OF MOTOR DRIVING ROLLS

While rolling a 5250 lb. slab, 4½ inches thick and 46 inches wide to a plate 316 inches long, 73 inches wide and ⅝ inch thick.

The Design of Porcelain Insulators from the Ceramic Standpoint

G. I. Gilchrist and T. A. Klinefelter

THE manufacture of porcelain insulators involves the consideration of a number of factors aside from those of a mechanical and electrical nature. Practically every line and section of an insulator must be modified more or less from what would be strictly correct from the theoretical standpoint.

After the preparation of the clay by one of the processes previously described*, the insulators are made by hand or machine jiggering, by dry pressing, or by turning and casting. For each method particular tools and methods of handling the clay body are required. If the same body is used for each process, it will be found that not only must the design be modified especially for each but that different shrinkages take place, and a different texture and structure of the porcelain itself result. The designer must keep all of these conditions in mind, since every detail in manufacture may require a modification especially adapted to the process by which the insulator is to be made.

Since most high-tension insulators are made by the wet process, some of the important factors affecting design for this method will be given attention. The production of these insulators is accomplished by jiggering or by use of the hot press machine, the latter being a mechanical modification of jiggering. If the insulator is to be jiggered it will be formed in a one piece mold and set aside to dry for several hours. At the end of this time the plaster mold will have drawn out of the insulator a certain amount of water, causing it to shrink and loosen from the mold. The mold is turned upside down and the insulator should slip out instantly, requiring no jarring or pounding. Being only partially dry, a heavy, or sometimes a slight jar will distort the shape of the insulator. Any subsequent attempt to restore the shape may set up enough internal strain to result in cracked or distorted ware during the burn. Obviously the insulator must have enough slope or draft so that it will slip out at once, when the mold is inverted. For the same reason, and also because of the shrinkage, there must be no shoulders or projections to catch on the mold when the piece starts to pull away from it.

*See article on "Electrical Porcelain" by the authors in the Journal for Feb. and March 1918, pp. 36 and 77.

The inner part of the insulator is formed by a shoe which either comes down in the arc of a circle, or drops vertically. If the insulator is a deep one, the designer must be careful that the jigger shoe, as it lifts out, will not gouge and distort the formed piece, otherwise the shoe must be dropped vertically, which is more expensive.

In some types of insulators, especially the suspension type, there are a number of corrugations. These must not be too thin or too deep. The thinner and deeper they are the more difficult it is to make the insulator. In a practical design the width of the corrugation should increase with the depth.

While the hot press machine jiggers automatically and hence should give greater accuracy in forming, it also gives a greater amount of trouble in other respects which do not appear in hand jiggering.

The clay body is difficult to keep absolutely uniform in moisture content and working quality and tex-

FIG. 1—HOT PRESS MACHINE

ture. On the jigger wheel this is easily taken care of, as the workman can use a little more or a little less water, and in general he can work the clay a trifle more and obtain a good product. With the hot press machine no matter what the condition of the clay, it receives the same treatment. Sometimes internal stresses result, due to the twisting motion of the plunger; sometimes it is simply an annoying sticking of the clay to the plunger, etc. These various things can be modified to some extent by proper design. Very thin petticoats, for instance, are likely to suck and draw, or stick to the die if the clay is a trifle too soft. An insulator with fins (such as a few of the small pintype), which in the mold constitute side passages, are hard to fill properly if the clay is not in quite proper working condition. Obviously too, these side passages will not be packed so tightly as the clay receiving the main thrust of the plunger. This results in a variation of shrinkage with subsequent cracking, if the stress set up becomes too great. Incidently an objectionable feature of insulators with fins is that they must be made in a split mold. Since it is possible to use a mold split in half on these machines, there has been a tendency to design shapes which can be made in no other way. The practice is bad, however, not only from the standpoint of cost, due

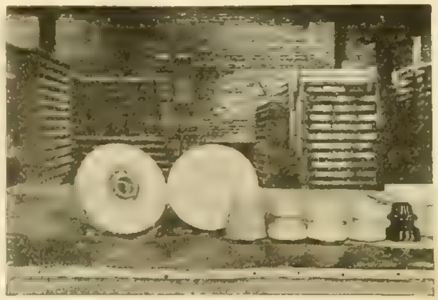


FIG. 2—HOT PRESS INSULATORS IN VARIOUS STAGES OF PRODUCTION

From left to right: 1—Insulator in mould. 2—Plaster of paris mould. 3—Insulator removed from mould. 4—Insulator trimmed. 5—Insulator bone dry. 6—Insulator glazed. 7—Insulator fired.

to greater breakage of molds, but the insulators are likely to be of inferior quality, and are more likely to have internal strains set up in them, with resulting loss by cracking.

One of these hot press machines is shown in Fig. 1, and Fig. 2 shows a mold, an insulator just moved from the mold, a trimmed unit, a dried unit, a glazed unit and a burned unit. An interesting investigation was recently conducted, covering the manufacture of several thousand of these insulators in an effort to determine the various factors causing the differences in ware made on these hot press machines. First, the pugged blank from which the insulator is made was varied. In one case a cylinder of clay of just the right diameter was tried, then a large cylinder divided into quarters and halves. The blanks were run soft, then quite stiff. Finally each different kind of blank was tested as to the best manner of patting into shape by hand, and throwing into the mold.

It was found that there was really a factor of considerable variation with each of these conditions. It makes a difference whether the clay is stiff or soft,

FIG. 3—FIRED INSULATORS IN SAGGER

After drawing from kiln.

the kind of blanks used, the method of handling the clay and throwing it into the mold, the general speed in working etc. Moreover, the accuracy of the machine itself is a factor, for if the plunger is not aligned correctly, the ware will crack very quickly on the inside.

The error in alignment may be so small as to be undetectable by the eye and yet cracking will result in less than a half hour. The human factor enters in at so many points that considerable differences are to be expected. A difference of ten percent in cracked ware

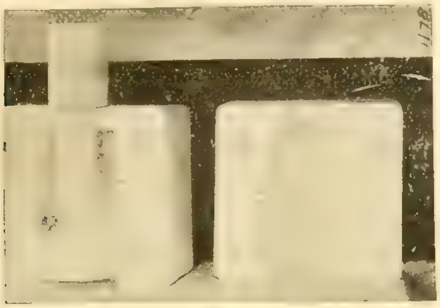


FIG. 4—CASTING MOULD

was found in the product of a number of long experienced hands.

On further study it is found that modifying the design changes the result of some of these factors greatly, some designs being extremely sensitive at stages of manufacture where others seem to stand almost any type of handling. The same factors regarding draft for removing the insulators from the mold applies to the hot press process as well as to the mold for hand jiggering. There are also the same limitations with regard to depth and thickness of corrugations.

After ware has been made by either process, it is ready for trimming, or it may be allowed to dry out thoroughly and then be trimmed. There are advantages in both ways, some designs being more easily handled one way than the other. In either case, the designers must consider how the ware is to be trimmed and what the limits are. There is a chance of breakage

FIG. 5—DRY PRESS MACHINE

and distortion in the trimming, especially if the piece has thin corrugations, or if it must be under cut. The less material there is to take off, the better, and the simpler and straighter the motions necessary, the better.

One of the main operations is drying. Here, aside from the factors already mentioned, the greatest and most important factor is that of section. Within reasonable limits, the thinner the section the better, since the drying takes place much more rapidly than where the section is thick. However, even more important is the necessity of keeping all sections as nearly uniform as possible. If this is done the shrinkage rate is practically the same throughout the piece and no new strains are set up. If, however, the thickness of a section changes abruptly, almost invariably cracks will appear in a large proportion of the insulators at the junction of the thick and thin parts. Too sharp a corner or abrupt a change in direction will also cause cracking. A change in direction should always take place gradually.

The sharp corner or edge is also sure to give trouble in respect to the next operation, that of glazing. Although the glaze becomes liquid during burning, it is generally quite viscous and the surface tension will pull the glaze away from sharp edges and flood abrupt corners. With a dark glaze this results in light lines on the edges, and dark in the corners, and some-

FIG. 6—DRY PRESS DIE AND FIRED INSULATORS

times crazing in the latter case if the glaze is too thick.

The final factors in the process deal with the kiln. The ordinary jiggered or hot pressed ware usually gives little trouble from warping, since it is generally heavy enough to hold its shape through the burn. Most of the trouble appears from too small a placing surface. The method of placing insulators in a sagger is shown in Fig. 3. Obviously the insulator must rest on one of its surfaces, which should be unglazed if possible. The designer too often gives this little attention and as a result the insulator has a small placing surface, and a high center of gravity. Therefore the least motion in the kiln causes it to upset, spoiling not only that particular piece of ware, but others near it.

If the surface is left glazed, it must be placed on some arrangement such as fireclay stilts or crushed quartz so that the glaze will not come in contact with the bottom of the sagger, with resultant sticking. Resorting to such methods is costly in itself and often results in a goodly percentage of pieces spoiled during the burn, through upsetting.

When ware is turned, the factors entering due to molds are eliminated. The main thing to be considered is the matter of section. There is a tendency for the designer to thicken a bushing abruptly in case he wishes a shoulder or ledge for clamping purposes. Thick

walls and small central holes are a combination to be avoided if possible since it makes a difficult piece to dry, as the air cannot get at the inside of the walls and dry them as rapidly as it does the outside. Corrugations must not be too thin and deep, or cracking takes place due to too abrupt a difference in thickness of section.

Finally the longer the tube, and the smaller its diameter, the more difficulty there will be in drying and firing without warping. Then too, such a tube is difficult and costly to place in the kiln. If too long to stand on its base, it must be hung from a shoulder in case there is any, or by some other method. As a result there is a fairly certain loss of a portion of the tubes, due to warping during the burn.

If the ware is to be cast, the designer has more leeway as to shape, since the molds are usually in sections. Fig. 4 gives a good idea of this. Here the main mold is in two halves, with a bottom piece and a core. This being the case it is readily seen that the outer surface need have no draft or slope, for instead of the insulator being dropped out of the mold, here the mold is taken away from the insulator. In case a core is used to form a hole in the center of the insulator, the more draft the better.

As the clay body goes into the mold in a liquid condition, and usually contains more water than an equal volume of jigger clay, the shrinkage is greater, and care must be exercised that corrugations or shoulders are not abrupt, or else the shrinkage will cause cracking before the mold can be removed. Once out of the mold, the drying and subsequent processes are exactly the same as in the case of the jiggered ware and the same factors enter.

Since the dry process is radically different in its method of forming, the factors governing design are modified more or less all along the line. It will be remembered that the moisture content is low to begin with, aproximately half of that of the jiggered ware, and the structure is more open and granular. A dry press machine is shown in operation in Fig. 5. The resemblance to the old fashioned printing press will be noted. Fig. 6 shows the two-piece die and a piece of burned ware formed by it. One part of the die is fixed in the lower part of the press. The other part is attached to a threaded bar and travels in a straight up-and-down motion as the bar is turned round.

It follows then, that the most effective pressure is the straight downward thrust, and hence any part of a piece which must be filled and packed by a lateral or angular thrust of the clay will be less compact in structure than that receiving the full down pressure. The designer must keep this fact before him constantly. Every hole, every projection must be studied from this angle. If all the rods for forming the holes can be put in vertically, well and good. All that is necessary then is to see that there is a slight draft to the rods so that the piece will lift out easily. In this case the ware will lift out with a single motion on the part of the workman.

If however, rods must run horizontally, trouble from cracking is likely, due to different rates of shrinking, since one part of the mass is more compact than the other. The clay above the rod and at the sides receives the direct pressure. Under the rods, however, the clay must flow in from the sides and be compacted by side thrust. Besides this, the operation is more costly, since the operator must slip these rods in place to start with, and then after forming the ware, slip them out before the piece can be lifted clear of the die.

Once formed, the piece will generally stand a little rougher treatment in the subsequent processes than jiggered ware of like weight, because of the lower water content and more open structure. Of course the sudden thickening of a section is to be avoided, although it does not cause so much trouble as with the wet process. This also applies to sudden change of direction. The need for rounded edges and corners remains as in the case of the other ware, the glaze acting the same in both instances. In the firing of dry press ware, there is generally more trouble due to thin flat sections, which are liable to warp, than to inadequate setting surface, owing to the nature of the ware made by the dry process in general.

Considering all these factors which play a part in design by whatever process, one factor appears of much importance. This is the matter of thickness of section, or rather the change of thickness in a piece. A slight adjustment here or there will usually remedy the faults, but an abrupt thickening of the walls of an insulator usually means trouble.

Excitation Characteristics of Alternators

Q. Graham

THE EFFECTS of load and power-factor on the excitation required by alternators of various types, and the relations between the amount of excitation and some of the other characteristics of the machines, are not always fully understood. The operating engineer is aware that the amount of excitation current required depends largely upon the power-factor of the load, but he may not have a definite idea of the relative effects of changes in k.v.a., and in power-factor. When it is considered that the maximum load that the machine can carry is quite often fixed by the upper limit of excitation, it is obvious that a knowledge of excitation characteristics is important.

The characteristics of four classes of generators will be considered:—

1—Small belt-driven generators ranging in capacity from 37 k.v.a. at 1200 r.p.m. to 300 k.v.a. at 600 r.p.m. These machines have a fairly high degree of satura-

tion, and are designed with a short-circuit ratio (ratio of field current at no-load and normal voltage to field current necessary to circulate full-load current on short-circuit) of from 0.95 to 1.1. They have reactances varying from 10 to 15 percent.

2—Engine-driven generators ranging from 100 to 1500 k.v.a., at speeds between 100 and 300 r.p.m. The machines in this class have less saturation than those in class 1. They have short-circuit ratios between 1.15 and 1.25 and reactances of from 20 to 25 percent.

3—Moderate-speed water-wheel driven generators from 150 to 6000 k.v.a. with a range of speeds from 300 to 720 r.p.m. The saturation curves of these machines show more *bend* than the engine type machines in class *2*, but not so much as the small belted type generators. They are designed with short-circuit ratios between 1.0 and 1.2, and have reactances of from 16 to 20 percent.

4—Turbogenerators of from 500 to 20 000 k.v.a. and at speeds of from 1500 to 3600 r.p.m. The average saturation curves for these machines have less bend than those of any of the other classes. The short-circuit ratios are between 1.0 and 1.2 and the reactances vary from 6 to 12 percent.

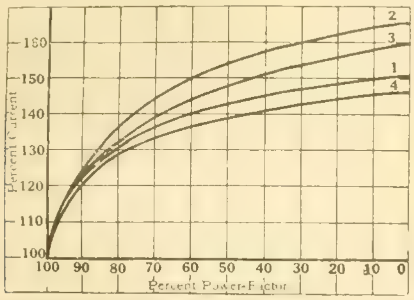


FIG. 1—INCREASE IN EXCITING CURRENT WITH DECREASED POWER-FACTOR

With k.v.a. output constant at full load. The numbers on the curves correspond to the four classes of generators described.

All of the generators in these four classes have single maximum ratings at 80 percent power-factor.

EFFECTS OF LOAD AND POWER-FACTOR

For a constant k.v.a. output, the field current must be adjusted for each different power-factor and a given change in power-factor requires a greater change in field current at high power-factors than at low power-factors.* Fig. 1 shows the relation between power-factor and percentage field current from unity power-factor to zero percent power-factor for the classes of machines discussed. Curve *4*, for example, shows that a change from 100 to 90 percent lagging power-factor requires an increase in field current of 20 percent, while a further decrease in power-factor to 80 percent, requires an additional increase in excitation of only seven percent. These curves have been obtained from tests on a large number of machines and give average values for the several classes of generators represented. Individual generators vary from these curves, the variation depending upon design proportions. The shapes of the curves will approximate these shown in Fig. 1, although the absolute values may vary from the average shown.

The relation between k.v.a. and percent field current at constant power factors, is shown in Fig. 2, the curves for 100 and 80 percent power-factor for all four classes of machines being shown as an illustration, though curves for any other power-factor could have been used. In fact, it is possible to approximate the curves for any other power-factor by making use of Fig. 1. For example, if the curve for 60 percent power-factor is desired for a machine say in class *2*, reference to Fig. 1 shows that at 60 percent power-factor and full load k.v.a. the excitation is 150 percent of its value at 100 percent power-factor and full k.v.a. Fig. 2 shows that under this latter condition the excitation is 139 percent of no-load excitation. Then 139 percent multiplied by 1.50 gives 208 as the percent of no-load excitation that is required for full load k.v.a.

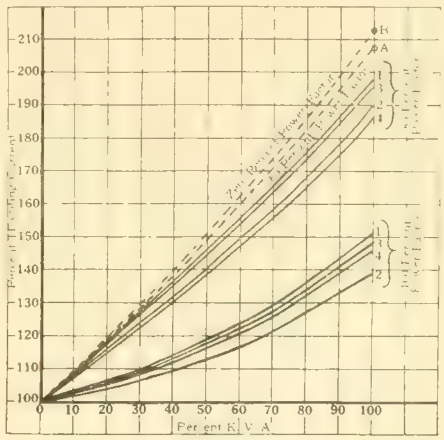


FIG. 2—INCREASE IN EXCITING CURRENT WITH LOAD AT CONSTANT POWER-FACTOR

at 60 percent power-factor. This value plotted on Fig. 2 gives point *A*. If a curve which follows the curvature of the 80 percent power-factor curves be drawn from this point to the origin it will be very nearly as accurate as if it had been worked up from the original test data. In a similar manner, the curves for any other power-factor could be drawn with a fair degree of accuracy. It will be seen that the curves for the lower power-factors are much the steeper, which is simply another way of saying that the range of excitation is greater with low power-factor loads than with loads of high power-factor. In comparing these curves with those in Fig. 1, it must be remembered that in one case the percentage is based on the field current for no load, while in the other it is based on the field current for full k.v.a. and 100 percent power-factor.

The curves given in Figs. 1 and 2 apply to the average of the machines in the classes which they represent. The reasons for the differences between these classes of machines may be given in a general way, although they cannot readily be stated exactly or definitely, since such a large number of factors are

*The theory of alternator excitation and the effects of changes in load and power-factor have been explained in detail in an article entitled "Variations of Alternator Excitation with Load," by Mr. F. D. Newbury in the JOURNAL for July 1918, p. 253.

involved. The ratio of the armature ampere-turns to the field ampere-turns, the length of air-gap, the percent reactance, the degree of saturation, and other features which are of interest mainly to the designer, all affect the excitation characteristics of the generator. For example, a machine having a small air-gap, and consequently a large ratio of armature ampere-turns to field ampere-turns, requires a small amount of excitation at no load. But for a given load current in the armature the increase in excitation is the same as if the machine had a larger air-gap, so the percentage increase is greater. The length of air-gap used is dependent, to a great extent, upon other considerations, such as mechanical clearances and pole-face losses, and these are affected by the size, speed and type of construction. The increase in field current is affected largely by the reactance, being greater in high reactance than in low reactance machines. The reactance itself varies from six to eight percent in high speed turbo-

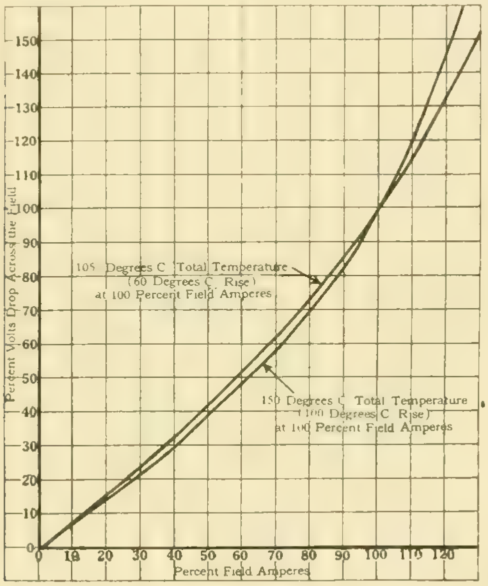


FIG. 3—VOLTAGE DROP ACROSS THE FIELDS AT DIFFERENT TEMPERATURES

generators to 25 to 30 percent in some of the slow-speed engine-type machines. For any given type and speed of machine, the reactance varies considerably, depending upon the shape of the slots and coils, the relative amounts of copper and iron in the machine and other features of design. The degree of saturation of the generator also has an effect upon the necessary increase of excitation with load; a highly saturated machine requires a greater increase in field current. In fact, there are so many factors affecting the excitation characteristics that no one set of curves can be made applicable to all machines. The best that can be done is to give curves and data based on the average of a number of actual machines.

MAXIMUM LOAD AS LIMITED BY FIELD

A knowledge of the field current required for any load and power-factor is of practical importance only in so far as it aids in determining the corresponding field temperature rise, the collector ring voltage or the exciter capacity, any of which may limit the maximum load of the generator. The field temperature rise, which is roughly proportional to the I^2R loss in the field winding, is not usually the limiting feature. This is true more particularly with the larger engine-type and water-wheel driven generators having strap-wound field coils and asbestos insulation, and with turbogenerators, the fields of which are mica-insulated and practically indestructible.

The voltage required at the field collector rings is quite often the limit to the capacity of the generator on account of the very definite limit to exciter voltage which exists in many stations. If the load becomes such that the fields require a higher voltage than is available, it will be impossible to maintain a constant voltage at the alternating-current busses. It must be realized that, as the field temperature is increased, due to higher current, there is a corresponding increase in field resistance. With the field excited for full load, the field winding resistance may be as much as 30 or 40 percent higher than its cold resistance. A higher voltage is thus required both because the current is higher and because there is an increase in resistance

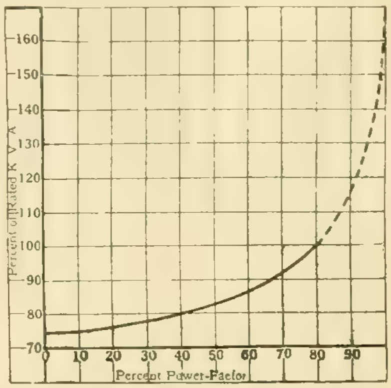


FIG. 4—EFFECT OF POWER-FACTOR ON THE K.V.A. OUTPUT

As limited by the temperature of the field, with constant field current.

which accompanies the higher current. In Fig. 3 is shown the relation between field current and field voltage, based on a 60 and on a 100 degrees C. rise at full-load field current. These curves illustrate the fact that the required field voltage increases with surprising rapidity when the generator is excited above its normal amount. For example, the curve based on 100 degrees C. rise, at full load, shows that for an increase of 20 percent above full-load field amperes, the field voltage must be increased from 100 to 145 percent. With a field having a 60 degrees C. rise normally, the increase in voltage is from 100 to 133 percent. In either case, the required increase in voltage is greater than can be obtained from most exciters, assuming that normal exciter voltage is required by the fields at 100 percent field current.

CHANGE OF RATING WITH POWER-FACTOR

In Fig. 4 is shown the effect of power-factor on the k.v.a. output of an alternator as limited by the field. It is assumed that the machine is rated at 80 percent power-factor and that the field current at this power-factor and full load k.v.a. is the maximum that can be

used. Then if the machine is to be operated at some other power-factor, its rating, as determined by the field, is that shown by Fig. 4. The part of the curve above 100 percent k.v.a. is dotted since the machine could not be operated at these higher armature currents in all cases, if it were a maximum rated machine. The curve simply shows the possible rating as determined by the field only. While this curve will not fit every case, it represents the average of a large number of modern 80 percent power-factor generators, and may be taken as a fairly close indication of the reduction in rating which must follow a reduction of power-factor. If a decrease in rating is desired, based on a higher initial power-factor, this can be calculated, using the value for the desired initial power-factor indicated by the dotted part of the curve as 100 percent rating; but it should be remembered that the percentage decrease in rating will usually be somewhat greater than so determined in generators actually designed for the higher power-factor. This is due to the fact that generators designed for operation at high power-factors may safely be designed with lower short-circuit ratio and with greater saturation than normally used in generators designed for 80 percent power factor operation.

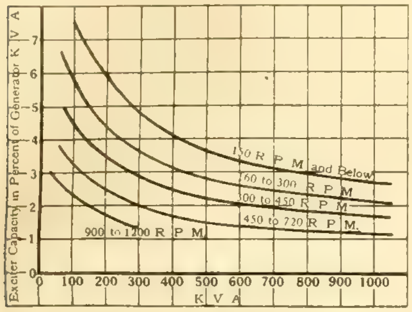


FIG. 5—PERCENT EXCITING KW REQUIRED FOR ALTERNATING-CURRENT GENERATORS BELOW 1000 K.V.A.

PRACTICAL PROBLEMS

The use of the curves here given may be illustrated by means of a few practical problems.

1—Voltage regulators of some types can handle only a limited range in exciting voltage. What is the total range in exciting voltage from no load to rated load, 80 percent power-factor in (a) a turbogenerator with 100 degrees C. rise; (b) a water-wheel generator with 60 degrees C. rise?

From Fig. 2, the range of field current for a turbogenerator rated at 80 percent power-factor is from 100 to 186 percent. Changing these figures in order to use full-load field amperes as the basis for the percentages, the total range becomes 100 percent as a maximum to 100 ÷ 186 or 54 percent as a minimum. Fig. 3 shows that with this range of current the voltage range is from 100 to 42 percent. Similarly, for a water-wheel generator, Fig. 2 shows the range of field current to be from 100 to 195 percent. With the change of basis for the percentages this range becomes 100 to 51 percent, and from Fig. 3, using the curve for 60 degrees C. rise, the voltage range is found to be from 100 to 44 percent.

2—If the field current and field voltage at rated load, 80 percent power-factor of a turbogenerator are known, what will be the field current and field voltage at same k.v.a. load, but 60 percent power-factor?

From Fig. 1, the field current at 80 percent power-factor is 129 percent and at 60 percent power-factor it is 137 percent. The 60 percent power-factor excitation is therefore 6 percent greater than the 80 percent power-factor excitation. If the temperature at full load, 80 percent power-factor is 100 degrees, the increase in voltage at 6 percent greater current will be 10 percent, from Fig. 3.

3—Due to a breakdown of one of the exciters in a power station, the available exciting current for each machine is limited to 75 percent of normal. With this limited supply of excitation, what is the maximum k.v.a. which can be carried by an engine-type generator at its rated power-factor of 80 percent? What is the lowest power-factor load, at rated k.v.a., that can be carried?

Referring to Fig. 2, the exciting current at full-load 80 percent power-factor is 190 percent of the no-load value. The available current is 75 percent of 190 percent, which is 142 percent. The k.v.a. corresponding to 142 percent field current is 52 percent of rated k.v.a. The second part of the problem is solved by means of Fig. 1, curve 2 which shows that the excitation for rated k.v.a., 80 percent power-factor, is 137 percent, based on 100 percent power-factor excitation. Then, 75 percent of 137 percent is 103 percent, the available excitation. The power-factor corresponding to 103 percent is practically 100 percent, which means that if rated k.v.a. is to be carried at the reduced field current, the power-factor of the load must be 100 percent.

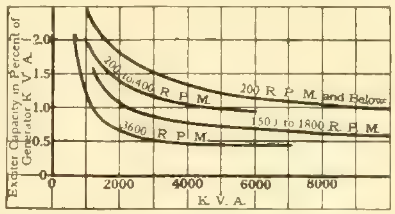


FIG. 6—PERCENT EXCITING KW OF LARGE ALTERNATING-CURRENT GENERATORS

4—If a generator is designed for 90 percent power-factor at rated load, what percentage of its rated capacity can it carry with the same field current and voltage at 60 percent power-factor?

The curve in Fig. 4 is drawn for a machine rated at 80 percent power-factor, but may be used for this problem also. The percent k.v.a. at 90 percent power-factor is 116, and at 60 percent power-factor is 87. Since 87 is 75 percent of 116, the machine will carry 75 percent of its rated capacity.

5—A synchronous motor is designed for operation at 80 percent power-factor. What percentage of its rated capacity can it carry as a synchronous condenser at zero percent power-factor, over-excited?

This can be taken directly from Fig. 4 which shows that 75 percent of rated k.v.a. at zero power-factor can be carried with the same field excitation.

6—Two turbogenerators are operating in parallel, each carrying 50 percent of rated k.v.a. at 80 percent power-factor. By adjusting the governors of the tur-

bines and the field rheostats of the generators one machine can be made to carry all the energy load and the other to carry all the reactive, or wattless, k.v.a. Under these conditions, will the total exciting current of the two machines be greater or less than under the present conditions?

Since each machine carries 50 percent of rated k.v.a. at 80 percent power-factor, the total load is 100 percent of the rated capacity of one machine at 80 percent power-factor. This load has an energy component of 80 percent of rated k. v. a., which is to be carried by one generator, and a reactive component of 60 percent of rated k.v.a., which is to be the load of the other generator. The field current for 80 percent of rated k.v.a. at 100 percent power-factor is 132 percent of no-load excitation, according to the curve for turbogenerators in Fig. 2. To obtain the excitation of the machine that carries the reactive load, it is necessary to establish a curve for zero percent power-factor similar to those in Fig. 2. From Fig. 1, the excitation for rated k.v.a. zero percent power-factor is found to be 146 percent of the excitation for 100 percent power-factor. Fig. 2 shows the 100 percent power-factor excitation at rated k.v.a. to be 146 percent of no-load excitation. Then 146 percent of 146 percent gives 213 percent as the excitation for rated k.v.a. zero percent power-factor, expressed as a percentage of no-load excitation. This value is plotted in Fig. 2, giving the point *B*, and an approximate curve is drawn. From this curve, the excitation at 60 percent of rated load is found to be 162 percent. Adding this to the 132 percent, which was obtained for the other machine, the total for the two machines is found to be 294 percent. Under the original conditions, with each machine carrying 50 percent k.v.a. at 80 percent power-factor, the excitation for each machine is 138 percent, from Fig. 2, and the total for the two machines is 276 percent. The total excitation is greater, therefore, under the proposed condition than under the original condition.

PERCENTAGE EXCITER CAPACITY

The percentage relation between exciter capacity and generator rating varies widely with machines of different speeds and design proportions. In alternators of the same design proportions, the percentage exciting kw is smaller with high-speed than with low-speed machines, and smaller with large capacity than with small capacity units. The curves in Figs. 5 and 6 show the influence of speed and capacity on the required excitation capacity of different types of alternators. The curves show average conditions only and should be considered approximate in any particular case.

In comparing two machines of the same rating, it may be found that the exciter capacities required are quite different. The two machines may require the same excitation at no-load, but if one is designed with relatively few armature conductors, and the other with a larger number of conductors, their full-load field currents will be quite different. The machine with the smaller number of conductors will have less increase due to its lower values of reactance and armature reaction. However, this machine will require a larger flux in order to generate the same voltage as the machine with the greater number of armature conductors, and to accommodate this flux a larger core section will be required. Thus, the machine having the smaller exciter will be the larger and heavier machine. While this means a more expensive design, the difference in cost is not to be judged directly by the difference in weight. The small flux, or light weight machine necessarily has a higher ratio of copper weight to total weight. Exciter capacity of alternative designs should, therefore, be judged only when consideration is given to the other related features. The tendency in generator design is to increase the percentage excitation, this being the result of higher armature reactance and reaction, and to build lighter weight and less costly machines.

CHOICE OF EXCITER VOLTAGE

The choice of exciter voltage, whether 250 or 125 volts, is not a matter of great importance in the majority of cases. Usually the machine can be designed for either voltage, and the decision is based on the greatest convenience to the purchaser, though the larger number of alternators use the lower of the two standard voltages. There are some cases, however, in which it is more desirable to use one than the other. A given machine requires a certain kw excitation regardless of the voltage, so that with the higher of the two voltages a lower current is required, and consequently a smaller size of conductor is used for the field coils. In machines of small capacity, this may result in a wire of such small cross-section and a coil of such a large number of turns that a large amount of the coil space is taken up by insulation. This is an uneconomical use of the space and gives a coil which is unable to dissipate heat rapidly. Trouble may also be experienced in high-speed machines, in supporting the coil properly against centrifugal force. In such a case, the use of 250 volts may be a real handicap. With 125 volt excitation, the coil would have fewer turns of larger wire, which would be more economical in its use of space, would be cheaper to build, and, due to the stiffness of the wire, would have less tendency to lose its shape. Small turbogenerators, or other machines on which it is desired to use copper strap bent on edge for the field coils, also have a lower limit for 250 volt excitation on account of the trouble experienced in bending the thin straps to the proper shape.

In some of the very large turbogenerators, the other limit is reached. That is, if 125 volt excitation is used, the current becomes so large that difficulties in current collection are encountered. In order to accommodate a large current it becomes necessary to equip the machine with heavy collector rings and a large number of brushes, which means an increased length of machine, as well as a possible source of trouble. In machines of this class, 250 volt excitation is more satisfactory.

Industrial Controllers-XXIV

Electrical Equipment for Oil Wells

H. D. James and W. L. Hartzell

OIL is used extensively today in industrial establishments and has entered into many phases of every day life. Next to coal, it is our principal source of power. Many of our battleships and merchant vessels, and railway locomotives, use oil for fuel instead of coal. During 1917, the production of crude oil in the United States exceeded 340 000 000 barrels, which was worth nearly one billion dollars. After the oil was refined, it represented a much higher value. This production in the United States amounted to 65 percent of the world's total production of crude oil. The distribution of oil wells in the United States may be divided broadly into five fields as follows:—

FIG. 1—A TRANSFORMER SUBSTATION IN AN OIL FIELD
With derricks in the background.

1—*Eastern or Appalachian Field*—These oils are generally of the paraffin base and are large producers of gasoline and lubricating oil. The wells are gaseous and gas engines are extensively used for pumping.

2—*The Mid-Continental Field, including Kansas, Oklahoma and Northern Texas*—This field produces oils having both paraffin and asphaltum bases. In this field, there are about 400 wells operated by electric motors and in the neighborhood of 1000 new wells are being equipped with electric drive.

3—*Louisiana and South Texas*—These oils are principally of the asphaltum base. The electric drive is just being introduced; and 100 new wells will be equipped in the near future.

4—*Colorado and Wyoming Field*—This field produces oil with a paraffin base. It is a new field and the development has been retarded by lack of material during the war.

5—*California Field*—The oil in this field has an asphaltum base and the pumping has been done by burning it under boilers to produce steam. This was very uneconomical and the electric drive has found its widest application here, there being now something over 2000 wells equipped with electric motors obtaining power from hydroelectric plants.

The introduction of electrical equipment for oil wells has been gradual, and there was much skepticism expressed at first as to the feasibility of this drive. It is dependent upon central station power for its economic operation and it is not probable that any considerable development will take place in fields which are not adjacent to large central station lines. In southern California, due to the far-sighted policy of two of the large power companies, this development has been carried forward rapidly. The power company supplies the high tension service to a centrally located substation where outdoor-type transformers step down the power to the low-voltage distributing system. The electric meters are located at this substation and the distribution is taken care of by the owners of the lease. In addition to pumping and pulling the wells, electric power is available for operating the machine shops, pumping stations, dehydrating plants, and for welding the pipe joints for pipe lines. It also furnishes light where required and can be made of general service throughout the whole lease. The use of welded joints on pipe lines is a comparatively recent development and is rapidly superseding the screw joints, where electric power is available for welding purposes. Welded joints remain tight and materially reduce the loss from leakage. The pipe sections can readily be cut apart with the electric arc, where renewals or changes are required.

FIG. 2—AN OIL WELL EQUIPMENT
Showing stands of tubing resting against the side of a derrick.

When an electric motor is applied to a well, it must perform two functions; namely, pumping and pulling.

The pumping service is used about 98 percent of the time. With the pulling service is included the lifting and lowering of tubing and tools, the cleaning of the well, which is known as "swabbing", "agitating", baling sand and other general work.

PUMPING

This application does not differ in any essentials from an ordinary pumping installation, as far as the electrical equipment is concerned. For the shallower wells, a squirrel-cage induction motor is commonly used, operating on what is known in the trade as "steel pumping power." This rig may also be used to pump water from gas wells. The motor is started by connecting it directly to the line, as only a small motor is required.

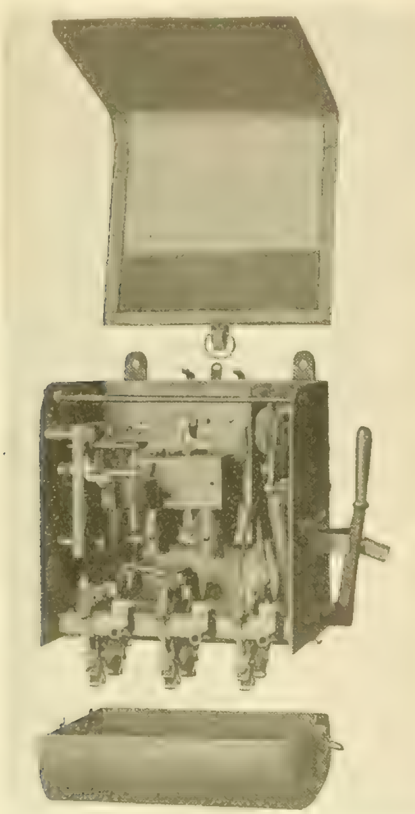


FIG. 3—COMBINED LINE SWITCH AND OIL CIRCUIT BREAKER WITH MAXIMUM TORQUE RELAY

For pumping service, the primary windings of the motor are connected in star and are protected by fuses.

Where the oil wells are shallow, another form of pumping power is sometimes used, known as a "band wheel power", which is connected to a number of wells, usually from 15 to 20. These wells are grouped together and pumped by means of pull rods running from the wells to the "power". By balancing one well against another, the pull can be distributed throughout the revolution of the band wheel and a remarkably small amount of torque is needed for operating the pumps. The band wheel is driven by a wound-secondary induction motor, so that the speed may be adjusted. When properly installed and connected up, the operation is very smooth and makes an ideal application for an electric motor.

Deep wells are pumped by individual motors of the wound-secondary type. These motors are started by inserting resistance in the secondary circuit. The primary is provided with low voltage protection and is connected to the line through a time element overload relay.

PULLING SERVICE

Under pulling service are included numerous miscellaneous operations. The principal function, however, is to pull the tubing out of the well and replace it. It is necessary to pull the tubing in order to clean out the well, when it becomes clogged with sand, or a new working barrel installed. During this time, the well is not producing oil and there is a direct loss of production. Furthermore, since oil is of a migratory nature, the operators feel that they are actually losing the oil which they do not pump. It is therefore desirable to reduce this inactive period as much as possible.

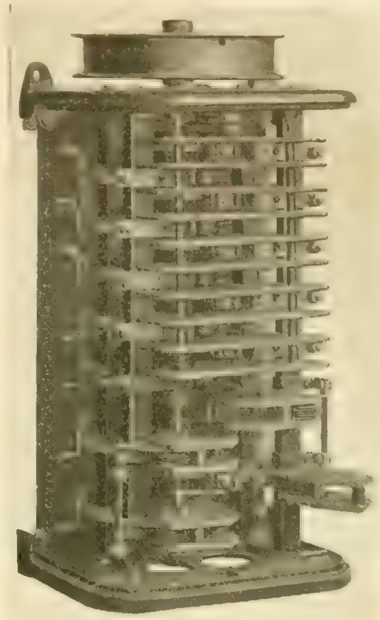


FIG. 4—CONTROLLER FOR MOTOR PRIMARY AND SECONDARY

This controller is made up of cam contactors operated by a sheave wheel. The contactors are mounted in a self-contained case similar to a drum controller.

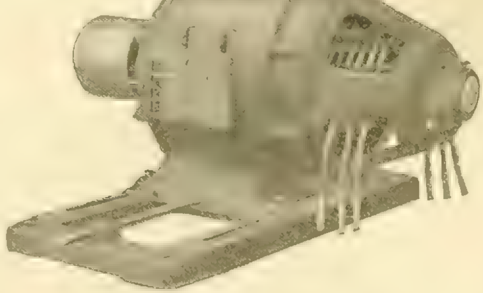
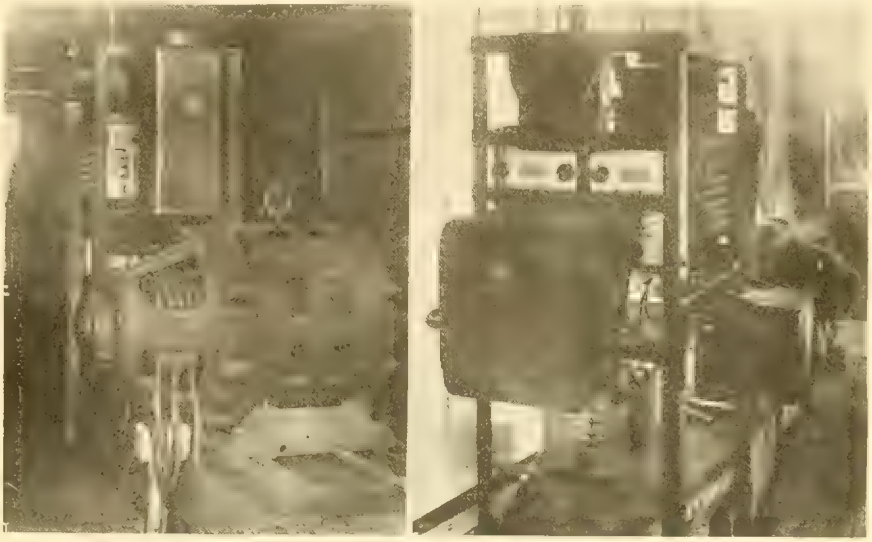


FIG. 5—TWO-SPEED WOUND-SECONDARY INDUCTION MOTOR

The time required for pulling the tubing and cleaning is proportional to the depth of the well. For shallow wells, which are pumped by squirrel cage motors, the pulling is effected by erecting an A-shaped derrick above the well and pulling the pipe out in short sections. The pumping motor can be used and the extra torque

for pulling purposes obtained by connecting the primary windings in delta. The motor is coupled to a hoisting drum by means of a clutch. Pulling service requires a reversal of the motor, which is obtained by the use of a small drum reverse switch. The motor is connected to the line by moving the drum switch to either the forward or reverse directions.

FIG. 6—MAXIMUM TORQUE SWITCH



FIGS. 8 AND 9—AN INSTALLATION OF A TWO-SPEED, WOUND-SECONDARY INDUCTION MOTOR USED FOR PUMPING AND PULLING

Deep wells, having a standard rig, use wound secondary motors, with the primary windings connected in star for pumping and in delta to get the extra torque for pulling. Usually the pulling torque is from three to four times the torque required for normal pumping. A

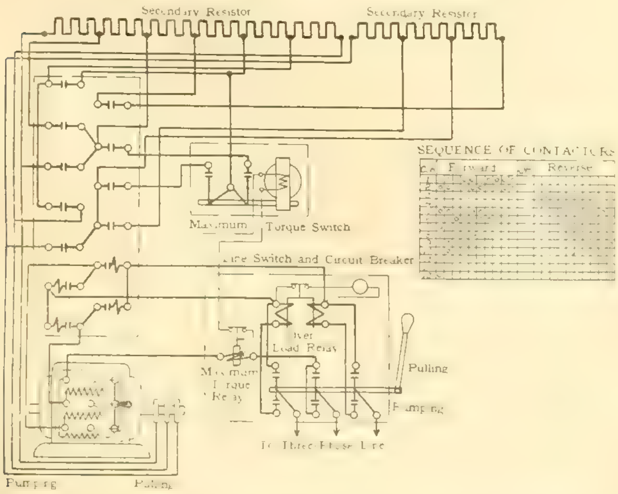


FIG. 7—DIAGRAM OF CONNECTIONS FOR A WOUND SECONDARY INDUCTION MOTOR

With primary connections in star for pumping and in delta for pulling.

double-throw switch is mounted on the frame of the motor which changes the connections from star to delta, the star side being marked "pumping" and the delta side "pulling". Where a two speed motor is used, the slow speed is for pumping and the high speed for pulling. The pump may operate for short intervals of time from the high speed connections for "shaking the well" or agitating the sand at the bottom of the well. Often this agitating will make it unnecessary to pull the tubing. It takes only a few minutes and may effect a considerable reduction in the idle period of the well.

The control of the squirrel cage motor presents no particular features. The windings of the motor are connected to a knife switch mounted on the motor frame, or other convenient location, for giving either the star or delta connection. The motor is started and stopped or reversed by a small drum switch which connects the primary windings directly to the line. The overload protection usually consists of fuses, the fuses being eliminated during the pulling period.

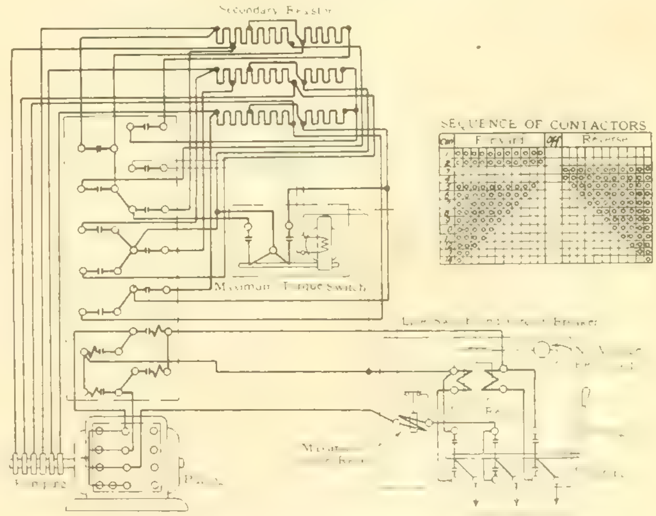


FIG. 10—DIAGRAM OF CONNECTIONS FOR WOUND SECONDARY TWO-SPEED INDUCTION MOTOR

The slow speed is for pumping and the higher speed for pulling.

The control for the wound secondary motor has several novel features. It consists of a combination line switch and circuit breaker, a controller with resistors to vary the speed of the motor, and a maximum torque switch. This switch consists of a three-pole double-throw contact member mounted in a case with a two-coil overload relay, a low voltage magnet and a maximum torque relay. The handle can be locked in

the central or off position to prevent accidental starting of the motor in case work is being done on the machinery. The two running positions of the handle are marked "pumping" and "pulling". When the handle is thrown into the pumping position, it is held in this position by the low voltage coil and the overload relays are connected in series with two legs of the motor circuit. In case of overload or low voltage, the handle is returned to the central position and the circuit opened at the contacts. When the handle is thrown to the "pulling" position, the primary of the motor is connected directly to the line with the maximum torque relay in series with one of the motor leads. The function of this relay will be described later. The secondary of the motor is connected to the controller, which is used for short-circuiting the secondary resistor. Only a part of used, or by connecting the windings to give half the number of poles where the two-speed type of motor is used. At the same time, the line switch is closed in the pulling position. With this switch in the pulling position, a maximum torque relay replaces the overload circuit breaker. This change is necessary to guard against an accident during the pulling process. If the motor becomes overloaded while pulling the tubing, instead of opening the circuit breaker as in ordinary service, the maximum torque relay will lift, operating the maximum torque switch which inserts the proper resistance in the motor secondary to give the maximum torque. The load applied may be sufficient to stall the motor when pulling, but the motor remains connected to the line exerting its maximum torque so there is no danger of dropping the tubing. If the motor primary were dis-

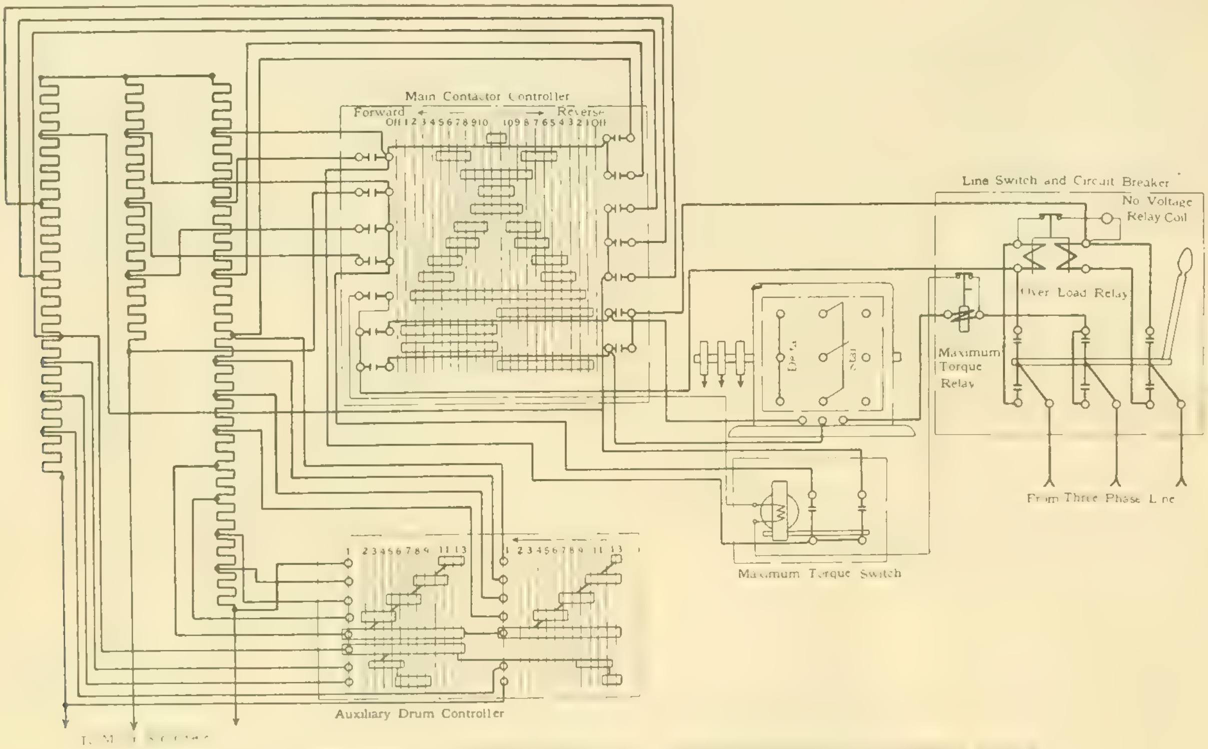


FIG. 11—DIAGRAM OF CONNECTIONS FOR A WOUND SECONDARY INDUCTION MOTOR

Equipped with an auxiliary controller for drilling. The motor primary is connected in star for drilling and in delta for pulling. The main controller is of the cam contactor design and the small auxiliary controller of the drum type.

this resistor is connected to the drum controller, one section in each phase being connected to a magnetic contactor, known as the "maximum torque switch". The coil of this switch is energized by the second point of the controller and remains closed during normal operation.

For pumping, the operation of the motor follows normal practice. The primary of the motor is connected to the line through the two overload relay coils and is provided with low voltage protection. The secondary resistance is used for starting and for regulation of motor speed when required.

For pulling service, the double-throw motor switch connects to the side marked "pulling". This connects the windings of the motor to give the high horse-power rating, either by changing them from the star connection to delta connection where a single-speed motor is connected from the line on overload, the tubing might drop down into the well at a high velocity. If the brake is applied and is successful in stopping the hoisting drum, the strain set up may be severe enough to strip the tubing apart at one of the couplings and drop a section to the bottom of the well. This results in a long and tedious "fishing" process during which time the well is non-productive. The star delta arrangement of primary winding is shown in Fig. 7. The combined line switch and circuit breaker is connected in the same way, but only one set of slip rings is required for the motor secondary.

DRILLING SERVICE

Where electric power is available, new wells are drilled with an electrical equipment. The drilling rig is substantially the same as that used with an engine, except that a motor is used instead of the engine.

Drilling is effected by attaching the string of tools to the end of a rope or cable. The lower end of this string of tools is provided with a cutting edge and the drilling is effected by alternately raising and dropping this string of tools in such a manner as to impinge upon the rock surface. The weight of this string of tools varies from 500 to 2000 pounds, depending upon the size of the rig. The force, with which it strikes the rock depends upon its stored energy at the time the blow is delivered. This energy is proportional to the weight of the tools, multiplied by the square of the velocity, or speed. The speed is imparted to the tools by allowing them to fall through a short distance. The rope is attached to a crank motion on the drilling rig, which is rotated by the motor. The speed of this rotation has an important bearing upon the strength of blow delivered by the tools. The alternate up and down motion of the string of tools and cable has a definite

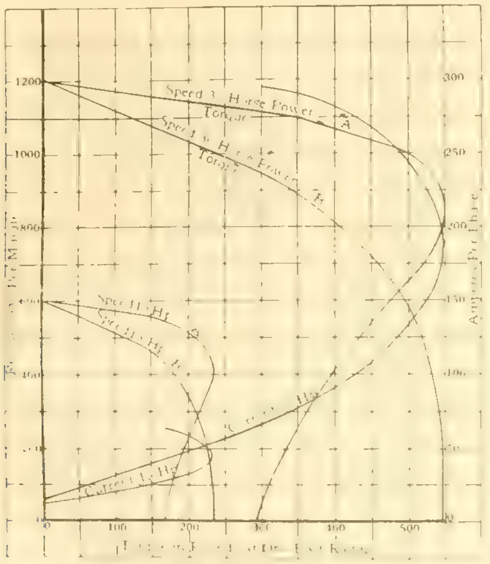


FIG. 12—SPEED TORQUE CURVE OF A TWO-POLE, WOUND-SECONDARY INDUCTION MOTOR, HAVING A RATING OF 15 AND 30 HORSE-POWER

These curves show very clearly the operation of the maximum torque relay. From the speed torque curve for 30 hp marked *A*, is obtained the performance of the motor with a short-circuited secondary. This shows that the maximum torque is obtained at 850 r.p.m. If the motor is loaded beyond this point, the torque will decrease with the speed so that at zero speed, the torque has changed from 500 to 300 foot pounds. At this point, the current shown by the curve has increased from 200 to nearly 300 amperes, the full load current being in the neighborhood of 50 amperes. If the torque relay is set to operate at 200 amperes, when the current reaches this value the relay will open the maximum torque switch, inserting sufficient resistance to give the motor its maximum torque of 500 foot pounds at zero speed (curve B). When the relay operates, the current will drop from 200 to less than 100 amperes. As the motor decreases in speed, the current will gradually increase to the 200 ampere value. This not only reduces the demand on the line, but insures maximum torque being maintained during these abnormal conditions. In practice, the maximum torque relay would be set to operate at a lower value than above, depending upon circumstances.

time period. It is therefore necessary to adjust the speed of the motor so that the alternate pull and release of the cable synchronizes with this natural time element. An adjustment of this kind increases the upward movement of the string of tools and therefore stores up the maximum of energy with which to strike the blow. When the tool strikes, it rebounds and this adjustment continues the upward motion from the rebound without a pause. The driller can tell by the feel of his string of tools when he has adjusted for the proper speed. The correct speed changes with the depth of hole so that the speed adjustment given by the controller must be in small increments. This is obtained by furnishing an auxiliary controller which changes a short section of the secondary resistor in small steps. The total range of this small conductor need not exceed the range of one step on the large controller. The driller can adjust his main controller for approximately the correct speed and then make the fine adjustments on the auxiliary controller. The diagram of connections is shown in

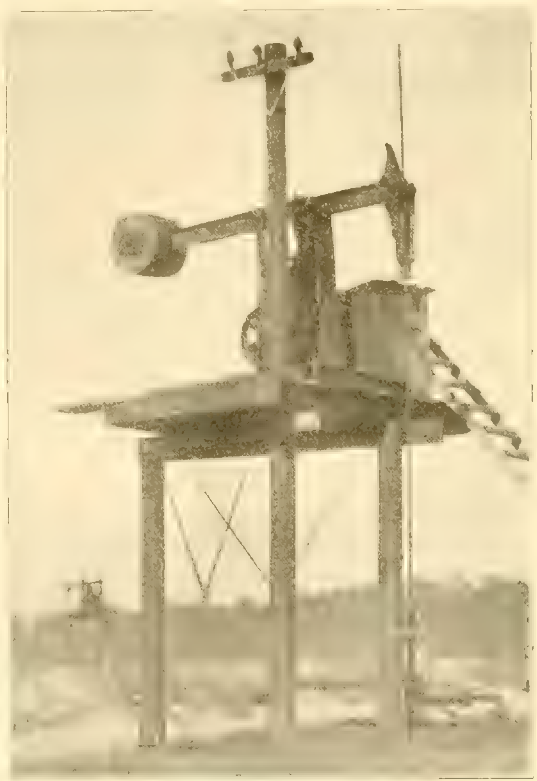


FIG. 13—STEEL PUMPING TOWER

The electric motor is located in the wooden enclosure at the right. The wells shown are in the bed of the Arkansas River in Oklahoma, the platform being raised above high water level. Pumping is continued during high water, the control being located on the river bank.

Fig. 9 and in every other respect is similar to the pumping and pulling controller shown in Fig. 7, the connections for the drilling side corresponding to the pumping side of the other equipment.

The motor used for a drilling rig is usually larger than for pumping, on account of the extra power required for handling the casing. In deep wells, the driller starts in with a large size casing and decreases the size as the depth of the hole increases. Sometimes the hole is not entirely straight, due to a boulder or other hard substance being located at one side of the hole. This deflects the drilling tool slightly. In putting the casing in past a crooked spot of this kind, it is necessary first to drop the casing and raise it again, repeating this operation a number of times until the casing passes down free of the obstruction. To do this with large casings requires motors which will develop from 100 to 150 horse-power for short intervals. Usual-

ly a motor connected in star for drilling and in delta for handling the casing is satisfactory. The delta connection would overheat the motor if it were operated in this way for long periods of time, but the pulling operation is short and the motor can be designed for continuous operation on the star connection only.

The motors for both pumping and drilling should have a high efficiency and power-factor, as these operations are continuous and the performance of the motor materially affects the power consumption. The introduction of electric motors and controllers has increased the production and earnings of oil wells on account of the ease with which the exact speed can be adjusted. The aim of the operator is to get maximum production at all times. There must be a minimum of delays due to breakdowns or repairs. Every shut-down means less production and a loss to the producer. The electric equipment has demonstrated its ability to furnish this service with a minimum of repairs and attention. In many cases the cost of the electrical power is more than made up by reduction in the repairs which were formerly necessary with the older methods of drive. In addition, the increase in production has been a material factor in the success of the electrical equipment. Electric drive is now being adopted in the oil fields as rapidly as central station power is made available.

Economical Ratio of Copper to Iron Loss

For Distribution Transformers

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THERE has been some discussion as to the most economical ratio, from the operating point of view, of the copper to the iron loss for distributing transformers. In the past this ratio for the 2300 to 230-115 volt, 60 cycle line of transformers, has been approximately *1.5* for the smaller ratings in the neighborhood of the one k.v.a. size, and ranging up to *2.5* for the 50 k.v.a. transformers. There are now advocates for an increase of this ratio to as high as *6* for the medium and larger sizes of transformers, the argument being that the iron loss is continuous for the full 24 hours, while the copper loss is equivalent on the average to a period of four hours at normal rated load.

The fallacy of this reasoning lies in the fact that, in evaluating the losses, not only the production cost of the energy consumed must be taken into account, but also the annual charge on the extra equipment which must be provided to supply the losses during the peak load period.

It is well known that the cost of making electrical energy is made up of two main elements:—

1—Production cost
2—Fixed charges

The items making up the production cost are those which vary with the amount of energy produced, such as fuel, lubricants, water, etc. The items making up the total fixed charges are those which are practically independent of the total energy produced, such as the investment and administration charges. The investment charge is made up of interest, taxes, insurance and depreciation on a power station and distribution system of sufficient capacity to supply the maximum demand of the total connected load. The administration cost is for the salaries of officials and for general office expenses.

In the following example it will be assumed that the production cost for a load having a 20 percent load factor is one cent per kilowatt-hour and under the same conditions the fixed charge is one-half cent per kilowatt-hour. The term "load factor" used in this connection is the ratio of the average daily output to the maximum hour's demand. The production cost is usually specified in cents per kilowatt-hour, but it is more convenient to use this cost in dollars per watt year in the following calculations. To reduce cents per kilowatt-hour to dollars per watt year, multiply by $(24 \times 365) \div 10^5$ or 0.0876. Multiplying the above production and fixed charges by 0.0876 gives,—

Production charge ....$0.0876 per watt-year
Fixed charge ....$0.0438 per watt-year

Example:—What is the yearly cost of operating a 50 k.v.a., 60 cycle, 2300 to 230-115 volt transformer, which has an iron loss of 260 watts and a copper loss by wattmeter at 75 degrees C. at normal rated output of 600 watts?

Since the iron loss is continuous and the copper loss exists for only four hours per day or 4/24 of the time, the yearly production cost of the iron loss in the transformer is $0.0876 × 260 or $22.78, and the cost of the copper loss is $0.0876 × 4/24 × 600 or $8.76, and the total production cost is $31.54.

Since both the iron loss and the copper loss occur at the peak load period, the yearly fixed charge for the losses, or the annual charge on account of the extra equipment which must be provided to supply this energy during the peak load period is $0.0438 × (260+600) or $37.67. The total yearly cost of the losses is therefore $31.54 plus 37.67 or $69.21. The cost of the transformer losses is figured in this way because the total cost of power for the entire station output must be the sum of the costs of the individual items making up the total load.

Table I gives the production cost, fixed charge and total cost for the losses resulting from the variation of the ratio of the copper to the iron loss. The exact values of the losses resulting from the variation of these ratios are based on the fact that the product of the losses remains constant if the different designs of the transformer to secure these losses are made with the same frame. With this assumption, the cost of the transformer is a constant quantity. Table I indicates that, with increasing values of the ratio of the losses, the production charge slowly decreases until a ratio of *6* is secured, above which it again gradually increases. The fixed charges have a constantly increasing value as the ratio increases. The sum of the production cost and fixed charge therefore becomes a minimum somewhere in the region of *2.3* as shown by Table I. The values in the table are plotted in Fig. 1. The lower

curve is for the production cost, and while it reaches a minimum value at a ratio of the copper to the iron loss of *6*, the curve is very flat and the production cost changes only through a range of about five percent of its value, for a variation of the ratio of the losses from *3* to *8*. It is not correct, therefore, even on the basis of the production cost alone, to say that one watt of iron loss is equal to six watts of copper loss.

The upper curve shows the total cost of supplying the transformer losses, and each point is the sum of the corresponding points on the two curves representing the production cost and fixed charge. The curves show how the addition of the constantly increasing value of the fixed charge to the production cost curve, reduces the point of minimum cost from a ratio of the losses of *6* to approximately *2.3*. It is also apparent that the total cost curve is fairly flat and the cost does not materially change for a range of variation of the loss ratio from *2* to *3*.

It might be argued that general conclusions should not be drawn from the particular values used for the production cost and fixed charge for power, in the example given. A little consideration, however, will show that the figures used for these quantities do not fix the shape of the production cost curve or the slope of the

TABLE I—ANNUAL COST OF TRANSFORMER LOSSES OF A 50 K.V.A. TRANSFORMER

Ratio of Copper to Iron Loss	Iron Loss	Copper Loss	Production Cost of Transformer Losses	Fixed Charge for Transformer Losses	Total Cost of Transformer Losses
1	395	395	$40.30	$34.70	$75.00
2.3	260	600	31.54	37.67	69.21
6	162	965	28.20	49.50	77.70
10	125	1250	32.50	60.30	92.80

fixed charge line, but merely their position relative to each other. If the fixed charge is small compared to the production cost, the total cost curve will approximate that of the production cost curve, giving the minimum total cost for a relatively large ratio of the losses. On the other hand, if the fixed charge is large compared to the production cost, the total cost curve will approximate that of the fixed charge curve, giving the minimum total cost at a relatively small value of the ratio of the losses.

Two factors which have a bearing on the proper relation of the losses have not been taken into account. These are the copper loss on the primary side of the transformer due to its exciting current and the regulation of the transformer itself. The exciting current increases with the transformer iron loss but, while the primary copper loss due to this current is in the same class as iron loss, the amount by which the iron loss is thus increased would ordinarily have a small effect in increasing the most economical ratio of the losses.

The regulation of the transformer becomes poorer as the ratio of the losses increases. As a poor regulation means a loss of revenue due to a reduced amount of energy delivered on account of the fall in voltage, it is apparent that the cost of the regulation is a factor tending to reduce the ratio of the transformer losses. It is sometimes argued that induction regulators are ordinarily used to keep the secondary voltage of the transformers at a definite value. However, it is practically impossible to keep the secondary voltage on a distributing system of any size at a constant value. The U. S. Bureau of Standards has made the following statement bearing on this point.*

"On alternating-current circuits, good regulation is most readily accomplished by voltage, or potential regulators, either of the induction or step by step type. Induction regulators can ordinarily be relied upon to maintain a uniform voltage at all loads at the center of distribution to within one percent. As the peak load will usually occur at different times on different feeders, and as the necessary amount of compensation depends upon the load and the length of the feeder, it is evident that in many cases good regulation is only possible when each feeder is independently regulated."

"In addition to the voltage drop in feeders and in primary mains there is a voltage drop in transformers and secondary mains. These voltage drops cannot be

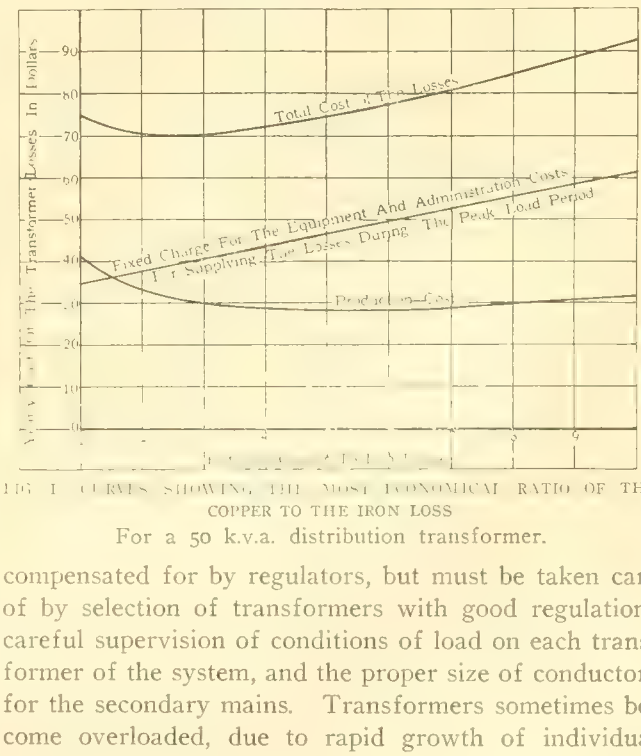

FIG. 1—CURVES SHOWING THE MOST ECONOMICAL RATIO OF THE COPPER TO THE IRON LOSS

For a 50 k.v.a. distribution transformer.

compensated for by regulators, but must be taken care of by selection of transformers with good regulation; careful supervision of conditions of load on each transformer of the system, and the proper size of conductors for the secondary mains. Transformers sometimes become overloaded, due to rapid growth of individual customer's loads, the number of customers to be supplied from one distributing point, and insufficient station records of transformer installations and their connected loads. It should be noted, too, that the regulation of transformers is dependent on the power-factor of the load, and some transformers, while giving good regulation on non-inductive loads, may cause large voltage drop at full load on mixed motor and lighting load."**

*From Circular of the Bureau of Standards, No. 56 on "Standards for Electric Service," pp. 16 and 17.

**For a further discussion of this subject, see Parts XII and XIII of the author's series of articles on "The Essentials of Transformer Practice," in the JOURNAL for July and Aug. 1918, pp. 276 and 315.

The Engineering Evolution of Electrical Apparatus—XXXV

The History of the Watt-Hour Meter in America

Chas. R. Riker

IN the earlier commercial applications of electricity, which were to arc lamps only, no meters were needed, as payment was made on a lamp-year basis. As the carbon incandescent lamp and the constant potential system of distribution came into use, charges for service were made on the same basis, that is, a certain sum per lamp per month. These early companies usually operated only from dusk to midnight, the lamps were seldom turned off and, as the cost of operation was to a considerable extent independent of the load, this system of charging was for a certain period not unsatisfactory. However, it was evident that some individuals or firms were using more electricity per lamp than others. As the dusk to midnight operation of the central stations gradually lengthened into all night and then into twenty-four hour service, the need of measuring devices became imperative. This gradual development of the central stations made it natural that the first meters should measure only the time during which the current was used; later both time and current strength, and finally watts and time were measured.

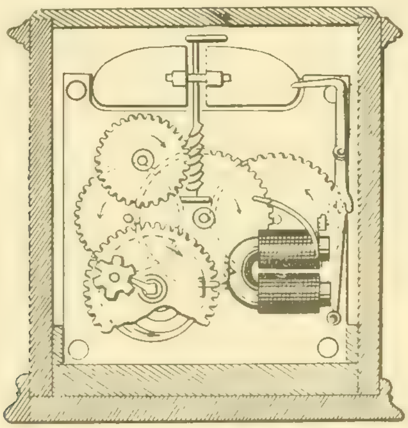

FIG. 1—GARDINER'S METER—1872

The first patent for an integrating-type meter was issued in 1872 to Samuel Gardiner, Jr. This meter, Fig. 1, consisted of a clockwork mechanism which was geared to a registering dial. An electromagnet, in series with the load to be measured, released the mechanism and allowed it to register the time during which current was passing. This device did not register either the current or electromotive force, but as the lamps were at that time controlled in groups, it furnished a satisfactory indication. Another ingenious device of this same general character for use on alternating current was patented by J. B. Fuller. As shown in Fig. 2, an armature of polarized steel was placed between two electromagnets so as to vibrate in synchronism with the alternations of the current in the magnets. The armature was attached to a lever having a pawl which engaged a ratchet and so operated a registrating mechanism as to give a measure of the time during which current was flowing.

Probably the first meter which registered both the current and the time was produced by Benj. F. Card and was based upon the principle that an iron rod will be drawn into a helix through which current is flowing. The movement of the core caused a friction wheel to slide along a clockwork driven cone, as shown in Fig. 3, in such a manner that the speed of the friction wheel was proportional to the movement of the iron core, and hence approximately proportional to the current in the helix. The friction wheel was geared directly with the registering dial.

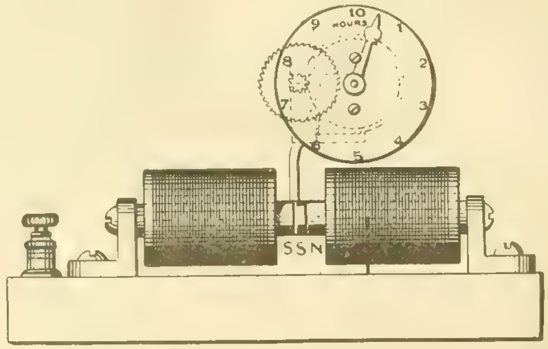

FIG. 2—FULLER'S ALTERNATING-CURRENT METER—1878

The first ampere-hour meter to be extensively used was the Edison chemical meter shown in Fig. 4, on which various patents were taken out. This meter, which was suitable for direct current only, consisted of an electrolytic cell containing two polished and amalgamated zinc plates immersed in a solution of zinc sulphate having a density of 1.11. One ampere of current would deposit in this meter 1.224 grams of zinc per hour. As this rate of deposit would require very large plates, the electrolytic cell was usually shunted with a German silver shunt of low resistance and a copper wire resistor was inserted in series with the electrolytic cell. Thus in the 12-light meter the shunt had a resistance of approximately 0.02 ohms, the cell three ohms and the copper wire resistor about 16.5 ohms, giving a total resistance in the meter circuit of 19.5 ohms. This provides a relation between the current in the line and that in the electrolytic cell of 1 to 975. The meter was "read" by removing the plates to a chemical laboratory where they were carefully dried and weighed and the ampere-hours calculated from the weight of the deposit and the known constant of the meter. Mr. Edison also developed a chemical type of "weber meter", as it was then known, in which the electrodes were suspended from a balanced beam. The

deposit of metal on an electrode caused it to sink gradually until an electric contact was made which caused the current to be reversed through the meter. The other electrode then gradually became heavier until it in turn made a contact, again reversing the current through the meter, the oscillations of the balance arm actuating a recording mechanism. In 1881 Mr. Edison invented a direct-current ampere-hour meter, Fig. 5, which was undoubtedly the first motor type of meter but which was never commercially developed, as Mr. Edison was evidently predisposed in favor of the chemical meter.

In 1880 Prof. Amos E. Dolbear produced a meter which, as shown in Fig. 6, was the crude forerunner of the graphic meter, and served for measuring both the current and the time during which it flowed. The paper rolls were actuated by a clockwork. The core of a helix was suspended in front of the paper by a spring

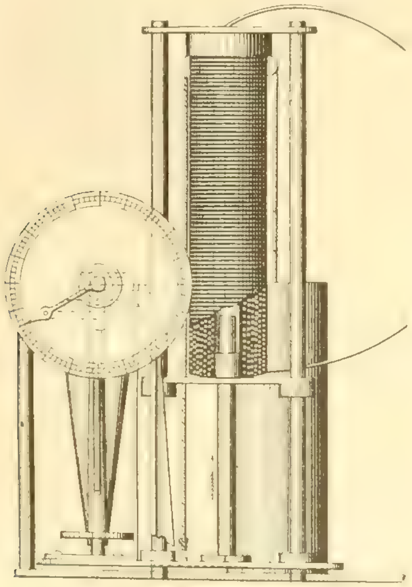

FIG. 3—CARD METER—1870

and carried a pencil which made a continuous mark on the paper, the position of the core being dependent on the strength of the current.

Various meters have been patented at different times based on the principle of having the speed of a clockwork mechanism varied by the action of an electromagnet on either the balance-wheel or the pendulum. With either type of clockwork the speed increases with an increase of current. The registration of the mechanism is not direct in these cases but must be compared with that of a similar mechanism which was not influenced by the magnets. By a variety of ingenious devices, the mechanism was also made to record only the difference between the two speeds, thus becoming direct reading. The most successful of these commercially was that by Dr. Arons, which was used extensively in Europe and to some extent in this country. As shown in Fig. 7, the right hand pendulum carried a coil of fine wire, shunted across the circuit, whose oscillation took place inside a coil of heavier wire which carried the main current. The interaction of the two magnetic fields increased the rapidity of oscillation of the pendulum, the increase being proportional to the product of volts and amperes. The dial train registered the difference between the oscillations of the two clocks. The meter was suitable for both alternating

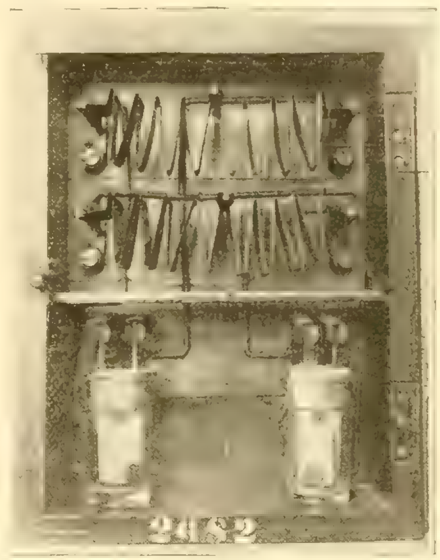

FIG. 4—EDISON ELECTROCHEMICAL METER—1878

and direct current and the clock work would run for 40 days with one winding. The objectionable features of this meter were its complexity and cost, and the peculiar readings which resulted if one clock stopped and the other continued to run.

The commercial development of the high-tension alternating-current parallel system of distribution and the accompanying extensive use of the hot-wire type of indicating instruments caused the development of various integrating meters whose action was based upon the heating action of the current. Among the first of these was one by Prof. Geo. Forbes of London. The heat produced in a resistor caused a rising current of

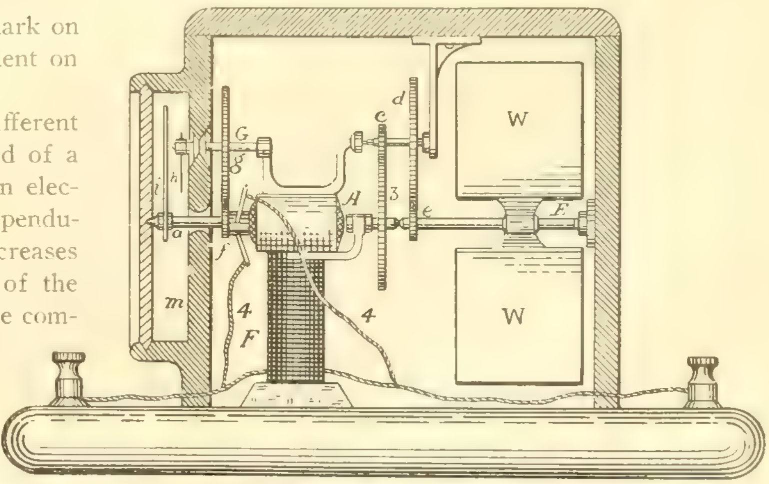

FIG. 5—EDISON MOTOR TYPE METER—1881

air which actuated a paper spiral or a mica and cork fan as shown in Fig. 8, the speed of rotation being roughly proportional to the current. This meter was extremely delicate and hence its usefulness was limited. In 1888 Prof. Elihu Thomson also developed a meter

based upon the heating effect of the current. It consisted of two evacuated glass bulbs connected by a small diameter tube and partly filled with alcohol, the whole being balanced so as to be slightly in unstable equilibrium. Each bulb contained a small electric heater which, in the bulb that was down at any instant, was connected to the circuit through mercury contacts. The heat in the coil raised the vapor tension

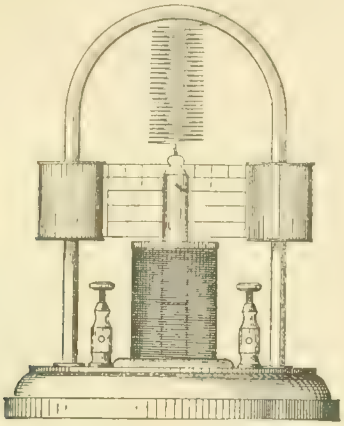

FIG. 6 DOLBEAR GRAPHIC INDICATING AND RECORDING METER—1880

and caused the alcohol to flow into the other bulb, which increased its weight and caused it to drop, establishing the contacts on that side and opening the first set. The oscillation of the bulbs operated the registering mechanism.

INDUCTION TYPE METERS

In April 1888, Mr. O. B. Shallenberger of the Westinghouse Electric Company devised the first commercially successful ampere-hour meter, i.e, the first one to have an extensive application and embodying

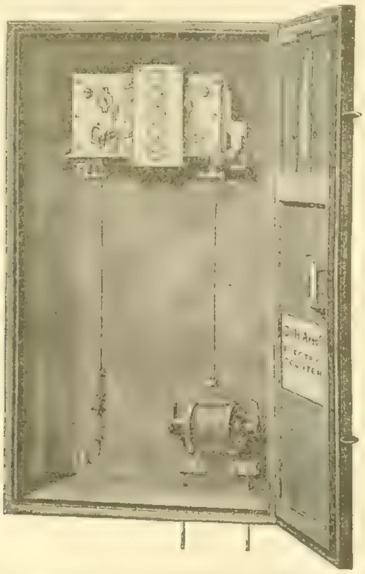

FIG. 7—ARON VOLT COULOMB INDICATOR—1887

principles which are still in use. Shallenberger's meter depended on magnetic induction and was described as follows:—If an alternating current be made to traverse a coiled conductor in proximity to two other conductors closed upon themselves, the secondary currents set up in these two conductors will correspond with each other to a greater or less extent in phase, and will be approximately in the same direction at the same instant, but both will differ in phase from the primary or inducing current. An attraction consequently takes place between the two secondary circuits and, if free to move, the conductors carrying these cur-

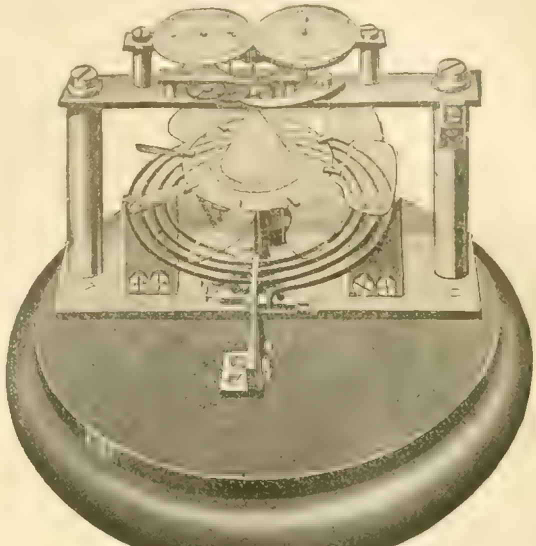

FIG. 8—FORBES METER—1886

rents will be attracted to each other in a greater or less degree, depending on the amount of the primary current and on the displacement of phase between the primary and secondary currents. If one of these conductors be made fixed and the other movable, the motion will evidently be confined to one of the conductors, and if the action can be continued so as to produce the attraction always in the same direction, a continuous, rotary motion may be obtained by the inductive action solely, and without any direct communication with the source of current.

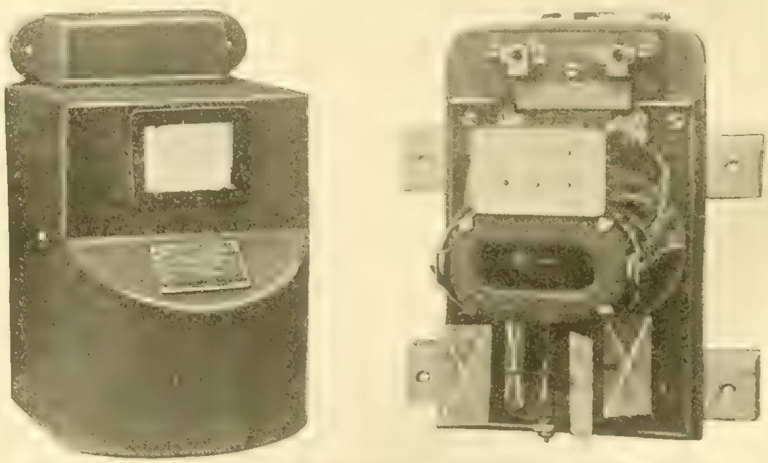

FIG. 9—SHALLENBERGER INDUCTION TYPE AMPERE-HOUR METER—1888

The discovery of this principle suggested at once the practicability of applying it to the operation of a meter, since it is only necessary to produce a rotary effort or torque in some simple and reliable way, bearing a definite relation to the current that produces it, in order to have a perfectly accurate means for measuring such current.

The form in which this meter was first marketed is shown in Figs. 9 and 10. It was found that one of the conductors mentioned above might be replaced by a core of iron with greater effect and much greater ease of construction. In Fig. 10, *a* is this flat ring of soft wrought iron mounted on a light disc of brass or aluminum and rigidly attached to a slender steel shaft.

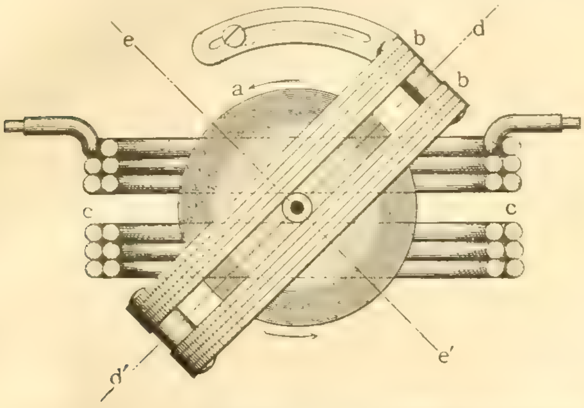

FIG. 10—OPERATING ELEMENTS OF SHALLENBERGER'S INITIAL INDUCTION METER

Short-circuited turns *bb* are punched from copper plates, riveted together at the ends, and so placed as to surround the disc closely without touching it, and adjustable in position with respect to the coil *cc* which is in series with the circuit to be measured. The torque is greatest when the plane of the coil *dd'* is at an angle of 45 degrees to that of coil *cc* and diminishes gradually as the position of the short-circuited turns *dd'* is changed toward *ee'*, being zero when the angle between *dd'* and *cc* is 90 degrees. This arrangement allows a wide range of speed adjustment. To provide a load on the meter element bearing the same relation to the speed as that of the torque to the current, a group of light

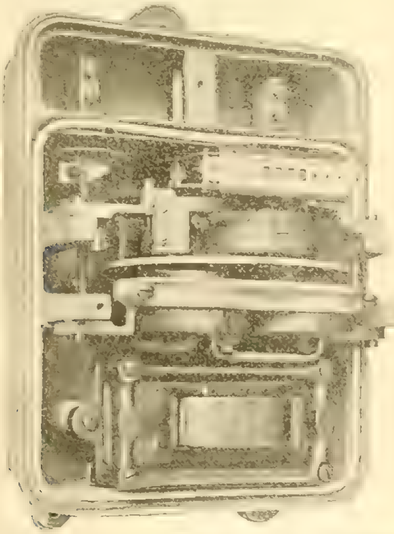

FIG. 11—SHALLENBERGER INTEGRATING WATTMETER—1894
This meter was provided with a cyclometer type register, giving the reading in plain figures, instead of on a dial.

fans was mounted on the shaft. On the meters of larger size a shunt coil was provided which gave sufficient torque, independent of the load, to overcome the friction of the meter and thus make it more accurate on light loads.

The weight of the moving element of this meter was slightly over one ounce, and the shaft pivot was supported on a jewel cup bearing. The meter was provided with a separate connection chamber, so that it could be installed without removing the case, thereby

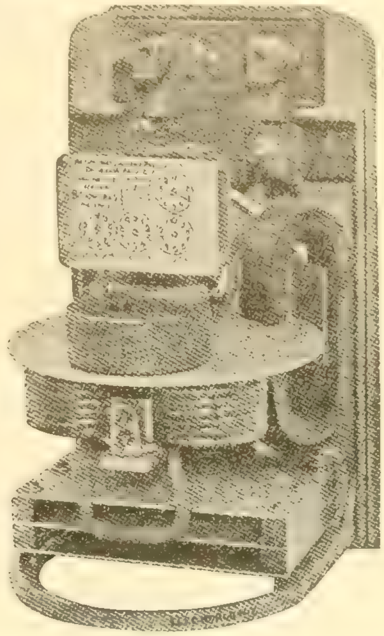

FIG 12—SHALLENBERGER POLYPHASE WATTMETER—1895

eliminating a possible cause of inaccuracy—a feature which is still incorporated in practically all modern meters.

This meter was quite satisfactory and was extensively used for a number of years. It soon became evident, however, that it was necessary in many cases to measure watt-hours rather than ampere-hours and in 1894 the Shallenberger watt-hour meter was produced, based upon the same general principle of design, including a shunt coil in place of the short-circuited secondary of the ampere-hour meter and with a suitable power-factor adjustment so that the fluxes produced by the two coils were at approximately 90 degrees relation to one another.

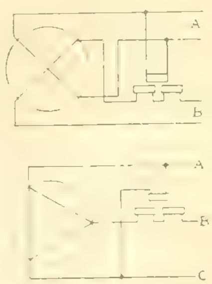

FIG 13—SCHEMATIC DIAGRAM OF CONNECTIONS TO TWO-PHASE AND THREE-PHASE CIRCUITS

This was the first meter in which the split phase principle was employed to obtain an approximately 90 degrees phase relation between the current in the shunt coils and the impressed e.m.f. This condition was secured by having the shunt coils consist of many turns of relatively low resistance wire around a laminated iron core having a small air-gap in the magnetic circuit.

With the development of the Niagara Falls power plant the requirement arose for polyphase meters, which were developed by Mr. Shallenberger, as shown in Fig. 12. The 90 degree phase relation in this meter was obtained by connecting the current coils in one phase and the shunt coil across the other phase, as shown in Fig. 13, thus being accurate only on balanced loads. Indicating instruments were also developed on

the same principle, by mounting a dial on the rotating disc and restraining its action by a spring.

In 1897 an important improvement over the Shallenberger watt-hour meter was brought out by Messrs. H. P. Davis and F. Conrad. This so called "round type" meter was on the same general principle as Shallenberger's but provided an exactly 90 degree phase displacement by including a separate induction coil in circuit with the shunt coils and by surrounding each limb of the core with one or more turns of wire short-circuited upon themselves through an adjustable resistance. The arrangement of the magnetic circuit in this meter was also such that substantially all of the series field and a proper portion of the shunt field acted directly upon the armature, while the entire shunt field operated to preserve constant the counter-electromotive force of the shunt circuit. This feature permitted an accurate registration of watts over a wide range of voltage, reducing the voltage error to a minimum. This meter represents the most important advance in meter design since Shallenberger's time. The Shallenberger

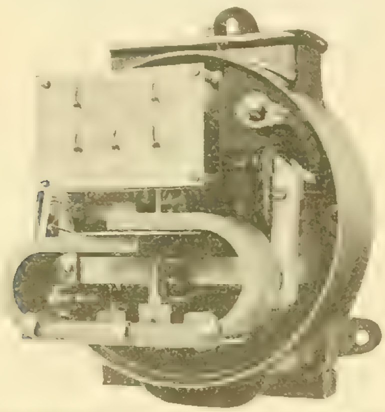

FIG. 14 — WESTINGHOUSE ROUND TYPE INDUCTION WATTMETER, 1897

meter was large and clumsy, heavy and expensive. The round type meter was relatively small and compact, was much lighter and sold for about one-third as much. In addition it was much more accurate. The polyphase watt-hour meter of this same general type consisted essentially of two single-phase elements mounted on the same shaft, and hence was the first one which would adequately measure an unbalanced polyphase load.

In this meter for the first time the importance of a light weight moving element was recognized. One means of lightening the weight was by removing entirely the aluminum fans and placing permanent magnets over the rotating disc thereby making this disc act both as a motor and generator element. The total weight of the moving element of the single-phase meter, was 15 grams, a weight which has been maintained practically constant in subsequent meters. This meter was both dust and bug proof and included a window in the case for viewing the rotating disc.

This meter included all the fundamental requirements of an induction meter and has been but little improved on in principle, most of the changes in more recent meters having been detail refinements in mechanical design and manufacturing operations, intended primarily to cheapen production. Among the most interesting of these mechanical improvements have been those tending toward the elimination of friction. The most important of these have been the ball bearings introduced by the Westinghouse Company, and the flotation principle of lifting the weight of the moving element entirely off the bearings. This was first introduced in the Stanley meters, in which the weight was carried by magnetism, the hollow shaft being restrained from side movements by a wire running through its center. Although an interesting development, this magnetic flotation is not used on any modern meters. Another improvement was the reduction of full-load speeds from around 50 to 25 r.p.m., thereby reducing the friction and bearing wear. This was made possible by a general redesign of the meter circuits, both magnetic and electric, so as to produce a much higher torque, and hence retain high accurancy at a lower speed.

FIG. 15 — ORIGINAL THOMSON RECORDING WATTMETER, 1889

Induction type meters have been and are manufactured in various forms, but all are based on the fundamental principles of the Shallenberger meter, and differ among themselves only in structural details.

COMMUTATOR METERS

In 1881 Edison secured patents on the motor type of direct-current meter but had never thought sufficiently of this device to develop it. In 1889, however, a successful motor type meter was developed, which became well known as the Thomson recording wattmeter, shown in Fig 15. Although of the type which is now almost exclusively used on direct-current circuits this meter was initially developed for alternating current, and its ability to meter either direct or alternating currents at any power-factor was in a great measure responsible for its initial success. This meter is in principle a modification of a Siemons dynamometer, the stationary coils being energized by the current in the main circuit and the movable coil shunted

across the line. The movable coils are so connected to a commutator that the active coil always bears the same relation to the stationary coils, so that the operation of the meter becomes that of a shunt motor, the torque being proportional to the product of the current and the voltage. It is also evident that when, on alternating circuits, the current and voltage were not in phase, the torque of the meter would be proportional to the current times that component of the voltage which was in phase, so that the registration would be correct at all power-factors. To provide a suitable load on the meter so that its speed might be at all times proportional to the torque, a copper disc was mounted on the shaft, revolving between permanent magnets.

The construction of this meter was carefully worked out mechanically. To prevent oxidation the commutator was made of silver, the brushes being made of flexible copper and silver plated at the point of contact. The armature, which was very heavy as com-

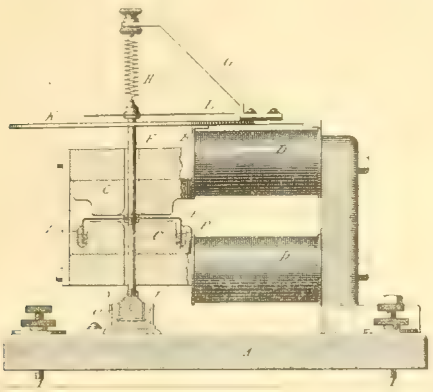

FIG. 16—WESTON MERCURY MOTOR METER 1886

The current to be measured passes through mercury contacts at *O* through the shaft and outward through the rotating disk to mercury contacts at *P*. In flowing thus across a magnetic field it caused rotation of the disk, the speed of rotation being proportional to the product of the current and field strength. The rotor weight was supported by a cork float, *N*.

pared with modern standards, weighing over half pound, was supported by a hardened steel removable point and jewel. When both were perfectly smooth the friction was very slight; the great weight of the moving element, however, was not favorable for a maintenance of this condition. The initial friction of the meter was compensated by a small coil in series with the armature circuit placed in parallel to the field windings. In the later types of meter this coil was made adjustable.

As was true of the early induction meters, this early Thomson meter was based upon sound principles, so that improvements which have been made since that time have been minor improvements in detail and in mechanical arrangement, rather than radical changes. One of the most important of the detail improvements was the introduction of the light weight spherical armature, and of an aluminum damping disk which permitted a material reduction of the total weight of the moving element. This general type of meter is now widely used for the measurement of direct-current power.

MERCURY METERS

In 1881, Weston patented an indicating ammeter which, as shown in Fig. 16, included all the elements of the modern mercury motor meters. Since he was designing an ammeter, the shunt circuit was highly saturated to render it independent of voltage fluctuations, and the rotation of the disk was restrained by a spiral spring. While this principle was then well known, being that of the Barlow wheel, Fig. 16 shows one of its earliest applications to an electric meter. The patent specifications included a statement that the instrument would be a true indicator of energy if the field magnet were not saturated.

This type of meter was developed as an ampere-hour meter in Europe by Ferranti but was never exten-

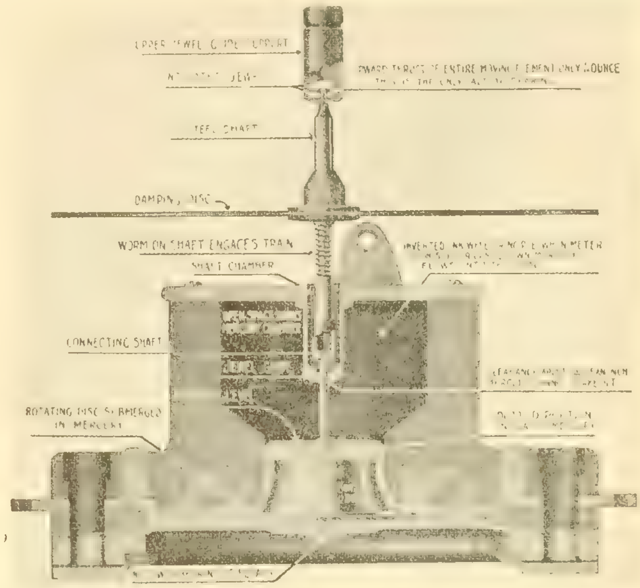

FIG. 17—SANGAMO MERCURY MOTOR WATT-HOUR METER

sively used in this country until in 1904 the Sangamo Electric Company brought out a model, much improved as to detail, but operating on the same basic principle. A more modern form of this meter is shown in Fig. 17, which shows the method of floating the moving element and the means provided to prevent spilling the mercury during transportation. In the watt-hour meters, the magnetic field is proportional to the voltage. In the ampere-hour meters a constant magnetic field is produced by permanent magnets. The current capacity of these meters is ten amperes, shunts being used in measuring larger circuits.

GENERAL

No attempt has been made to bring this history up to date, so far as the commercial forms of modern meters are concerned, but rather to show the development of the engineering principles upon which modern meters are based. Many important changes have been made in watt-hour meter construction in recent years which have tended to improve their accuracy and reliability, and to reduce their cost. These detail changes, which naturally have varied with each manufacturer, have been too numerous to include in a brief history of engineering principles.

Essentials of Transformer Practice-XVII

Three-Phase Transformation with Single-Phase Transformers

E. G. Reed

THE following discussion of three-phase transformation relates to the vector relations of the voltages and currents, the capacity of transformers required with the different arrangements and the regulation of the various groups. No mention is made of the peculiar conditions introduced by certain of these connections, or their relative value under operating conditions.

THREE SINGLE-PHASE TRANSFORMERS CONNECTED IN STAR OR DELTA

In a three-phase transformation the three primary or three secondary windings of the transformers may be connected in star or in delta. With the star connection the current in the windings is the current in the line, while the voltage of the windings is the line voltage divided by $\sqrt{3}$. The vector relations of the various quantities are shown in Fig. 1, the load having a 100 percent power-factor. This shows that, while the current and voltage in the windings themselves are in phase, the current I_{oa} in the line aA, for example, is 30 degrees out of phase from the voltage between the lines C and A or E_{CA}. With the delta connection, the voltage of the winding is the voltage of the line, and the current in each winding is the current in the line divided by $\sqrt{3}$. The vector relations of the voltages and currents are shown in Fig. 2, with a load having a 100 percent power-factor. In this case also, while the voltage and current in each of the windings are in phase, the current in the line cC for example is 30 degrees out of phase from the voltage between the lines B and C or E_{BC}. The k.v.a. transformer capacity required for a bank of star or delta connected transformers making a three-phase transformation, is equal to the k.v.a. transformed. This is not the case with some of the other connections for the same transformation. Greater transformer capacity required in some cases is due to the fact that the currents and voltages are out of phase, with a load having a 100 percent power-factor. The regulation of a single-phase transformer, connected in a star or delta connected bank, is the same as with the transformer operating single phase. With some of the other connections for the same transformation, conditions are introduced which affect the regulation of the group of transformers.

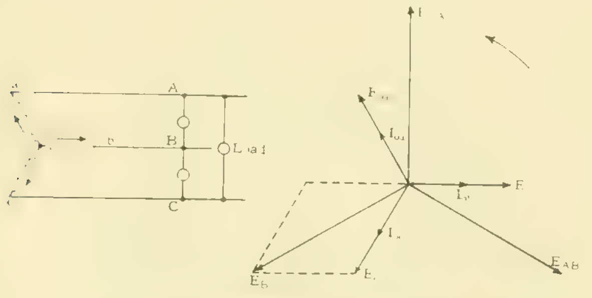

FIG. 1 THREE TRANSFORMERS CONNECTED IN STAR

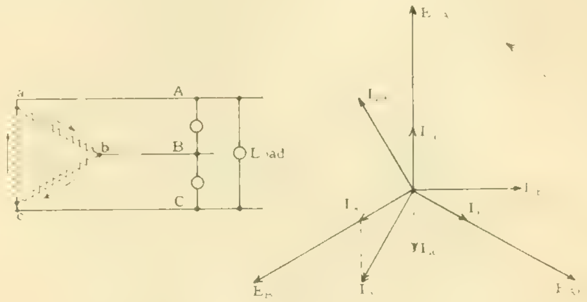

FIG. 2 —THREE TRANSFORMERS CONNECTED IN DELTA

TWO TRANSFORMERS CONNECTED IN OPEN DELTA

With the group of transformers connected in delta, as shown in Fig. 2, if one of the transformers, for example ac be removed, the two remaining transformers are left connected in open delta* as shown in Fig. 3. The voltage and current relations remain the same as with the delta connection and are shown in Fig. 3. The currents in the windings are now the currents in the lines, and the currents in the windings are 30 degrees out of phase from the voltages of the windings, as shown in Fig. 3. For this reason the ratio of the k.v.a. of transformer capacity required to the k.v.a. transformed is greater for this connection than with three transformers connected in delta. The k.v.a. transformed is $\frac{3EI}{\sqrt{3}}$, and the k.v.a. of transformer capacity required is $2EI$. Therefore,—

$$\frac{\text{K.v.a. of Transformer Capacity}}{\text{K.v.a. Transformed}} = \frac{2EI}{\frac{3EI}{\sqrt{3}}} = 1.15 \dots\dots\dots (1)$$

In other words, with the open delta connection 15 percent greater transformer capacity is required than the k.v.a. transformed.

Assuming a balanced three-phase load on the open delta bank of transformers and that the magnitude and phase relation of the primary impressed voltages remain constant, the regulation of the different phases may be approximated as follows:—

The vector relation of currents and voltages is shown in Fig. 4 for a load having a power-factor of 100 percent. The vector E_{BO} represents the vector sum of the voltage delivered by the transformer at full load E'_{BO} and the impedance drop through the transformer as shown by the impedance triangle. The IR component of the impedance triangle is in phase with the current I_{co}, and the reactive component is at right angles to this current. The current I_{co} is 30 degrees in advance of the voltage E'_{BO}, and the regulation is calcu-

*See article "The Open Delta Connection" by Mr. J. B. Gibbs in the JOURNAL for Feb. 1916, p. 100.

lated in the regular way for this condition. Therefore for the general case, from equations (11) and (12), section IV, the regulation for phase BC equals,—

$IR_1 \cos(\theta - 30°) \pm IX_1 \sin(\theta - 30°)$ .... (2)

Where IR_1 is the percent drop in voltage through the transformer in this phase, IX_1 is the corresponding percent reactive drop, and θ is the angle whose cosine is the power-factor of the load. The minus sign is to be used when the angle (θ—30°) is negative and the plus sign when the angle is positive; the angle θ being positive for a lagging power-factor and minus for a leading power-factor.

FIG. 3—TWO TRANSFORMERS CONNECTED IN OPEN DELTA

In a similar manner for phase AB, the IR component of the impedance triangle is in phase with the current I_{AB}, and the reactive element is at right angles to this current. Since the current I_{AB} is 30 degrees behind the voltage E_{AB} the regulation for phase AB equals,—

$IR_2 \cos(\theta + 30°) \pm IX_2 \sin(\theta + 30°)$ .... (3)

Where IR_2 and IX_2 are the percentage resistance and reactive drops in voltage through the transformer in this phase. The minus sign is to be used when the angle ($\theta + 30°$) is negative and the plus sign when the angle ($\theta + 30°$) is positive.

The drop in voltage across the phase CA is the sum of the two impedance triangles shown in Fig. 4. Since the IR components of these triangles are in phase with the currents I_{CC} and I_{BA} respectively, the phase relation of the voltage E_{CA} and the IR component of the equivalent impedance triangle across the phase CA can be determined. Since the two components of this equivalent impedance are approximately 120 degrees apart in phase the vector sum of the resistance and reactive components are, expressed in the symbolic notation,—

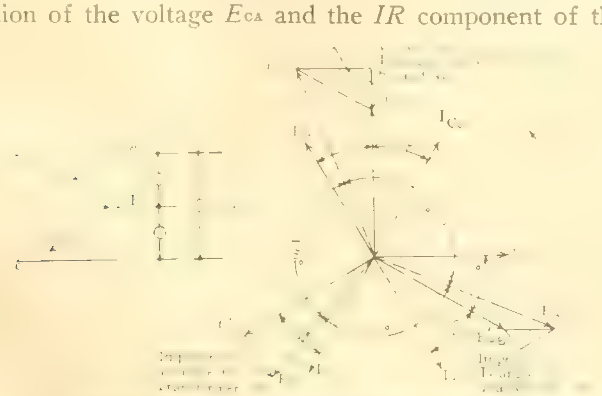

FIG. 4—REGULATION OF TWO TRANSFORMERS CONNECTED IN OPEN DELTA

For load having 100 percent power-factor.

$IR = 0.5\, IR_1 + IR_2 + j\, 0.866\, IR_1$ .... (4)

$IX = 0.5\, IX_1 + IX_2 + j\, 0.866\, IX_1$ .... (5)

The angle which the vector IR makes with the voltage E'_{CA} in Fig. 5, is,—

$$\tan^{-1} \frac{0.866\, IR_1}{0.5\, IR_1 + IR_2}$$

Therefore the angle,—

$$\phi = \theta + 30° - \tan^{-1} \frac{0.866\, IR_1}{0.5\, IR_1 + IR_2} \quad \text{.................... (6)}$$

Where θ is the angle whose cosine equals the power-factor of the load. The expression may now be written for the regulation of phase CA, which equals,—

$IR \cos\phi \pm IX \sin\phi$ .... (7)

The minus sign is to be used when the angle ϕ is negative and the plus sign when this angle is positive.

Example—Find the regulation, with an 80 percent power-factor load of two 5 k.v.a. transformers connected in open delta, the full load output of the bank being 6.93 kw, or such as to load the transformers to their normal rating of 5 k.v.a. each. The percent resistance and reactive drops of the transformers under these conditions being,—

For the phase BC, $IR_1 = 1.66$, $IX_1 = 2.32$

For the phase AB, $IR_2 = 2$, $IX_2 = 2.8$

The regulation of the phase BC, from equation (2),—

$= 1.66 \cos(37° - 30°) + 2.32 \sin(37° - 30°)$
$= 1.66 \times 0.992 + 2.32 \times 0.122 = 1.93$ *percent.*

The regulation of the phase AB from equation (3),—

$= 2 \cos(37° + 30°) + 2.8 \sin(37° + 30°)$
$= 2 \times 0.391 + 2.8 \times 0.92 = 3.36$ *percent.*

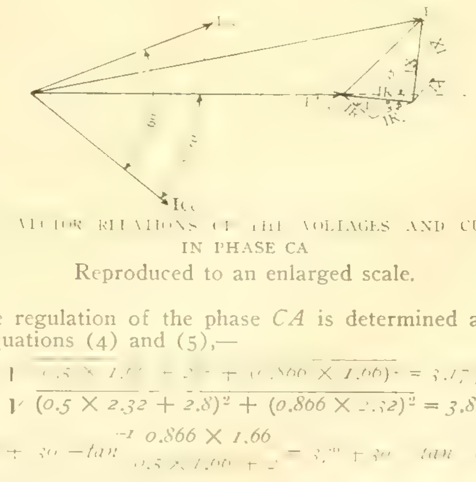

FIG. 5—VECTOR RELATIONS OF THE VOLTAGES AND CURRENTS IN PHASE CA

Reproduced to an enlarged scale.

The regulation of the phase CA is determined as follows from equations (4) and (5),—

$IR = \sqrt{(0.5 \times 1.66 + 2)^2 + (0.866 \times 1.66)^2} = 3.17$ *percent.*

$IX = \sqrt{(0.5 \times 2.32 + 2.8)^2 + (0.866 \times 2.32)^2} = 3.82$ *percent.*

$$\phi = 37° + 30° - \tan^{-1} \frac{0.866 \times 1.66}{0.5 \times 1.66 + 2} = 37° + 30° - \tan^{-1} 0.507 = 40°$$

Then from equation (7), the regulation of phase CA,—

$= 3.17 \times 0.766 + 3.82 \times 0.643 = 4.89$ *percent.*

The regulations for loads of 100 and 80 percent power-factors may be tabulated as follows:

Phase	For Loads of 100% Power-factor	For Loads of 80% Power-factor
E'_{BC}	0.28	1.93
E'_{AB}	3.13	3.36
E'_{CA}	3.37	4.89

TWO TRANSFORMERS CONNECTED IN T

Fig. 6 shows two transformers connected in T for a three-phase transformation, and the vector relation of the voltages and currents for a load having a 100 percent power-factor. It is evident that in the teaser transformer the current in the winding is in phase with the voltage of the winding, and in the main transformer the current is 30 degrees out of phase from the voltage.

The actual k.v.a. load on the transformer is therefore greater than the k.v.a. transformed. The k.v.a. transformed by the two transformers are $\frac{3\,EI}{\sqrt{3}}$, and the total transformer capacity is $EI + 0.866\,EI$. Hence,—

$$\frac{\textit{k.v.a. of transformer capacity}}{\textit{k.v.a. transformed}} = \frac{EI + 0.866\,EI}{\frac{3\,EI}{\sqrt{3}}} = 1.075 . (8)$$

If the main and teaser transformers are duplicates, as is usually the case, the above becomes,—

$$\frac{\textit{k.v.a. of transformer capacity}}{\textit{k.v.a. transformed}} = \frac{2\,EI}{\frac{3\,EI}{\sqrt{3}}} = 1.15 \quad \ldots\ldots\ldots \; (9)$$

which is the same as for two transformers connected in open delta.

While the k.v.a. of transformer capacity required, for the T connection is the same when the two units are duplicates as that for the open delta connection for the same transformation, the open delta arrangement is

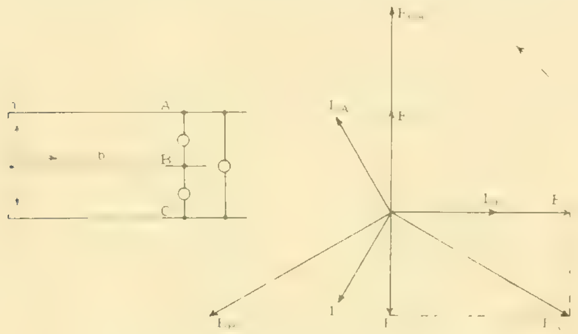

FIG. 6—TWO TRANSFORMERS CONNECTED IN T

ordinarily preferable. With the T connection the middle point of both primary and secondary windings must be available, and the design of the main transformer must be such that the impedance encountered by the current flowing through the teaser transformer and out through the main is not high, or the regulation of the group will be seriously impaired. With standard transformers the middle points of both windings are not always available, and the two parts of the windings are not always interconnected. The question of regulation for this connection is similar in some respects to that of two Scott-connected transformers making a three-phase to two-phase transformation.

INTERCONNECTED STAR CONNECTION

The vector relations of the voltages and currents for the interconnected star connection for a load having a 100 percent power-factor are shown in Fig. 7. The voltage E_{oc} equals $\sqrt{3}\,E_{oe}$, and the voltage E_{BC} equals $\sqrt{3}\,E_{oc}$. Therefore E_{oe} equals one-third E_{BC}. In other words each half of the secondary winding of each transformer has a voltage of one-third of the interconnected star voltage between the lines B and C or the

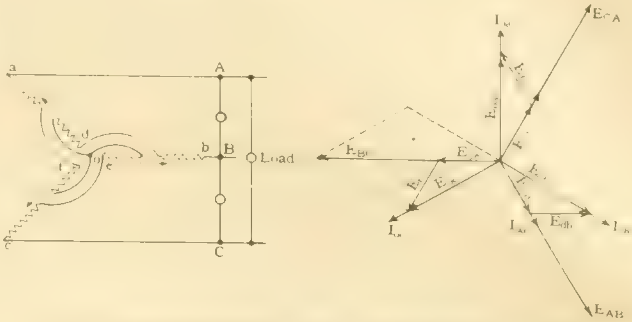

FIG. 7—INTERCONNECTED STAR CONNECTION OF THREE TRANSFORMERS

voltage E_{BC}. The voltage E_{oc} for example between the neutral point and one of the lines is 30 degrees out of phase with the voltages E_{oe} and E_{ec} of the two parts of secondary winding of the transformer of that phase. Therefore the k.v.a. transformed with this connection is less than the k.v.a. of transformer capacity required. The k.v.a. transformed is $\sqrt{3}\,EI$ in the primary side, whether connected delta or star (the delta connection is usually preferable) and is $6 \times 1\text{-}3\,EI$ in the secondary side. The total k.v.a. of transformer capacity is therefore $\frac{\sqrt{3}\,EI + 2\,EI}{2}$ and

$$\frac{\textit{k.v.a. of transformer capacity}}{\textit{k.v.a. transformed}} = \frac{\frac{\sqrt{3}\,EI + 2\,EI}{2}}{\frac{3\,EI}{\sqrt{3}}} = 1.075 \; (10)$$

A comparison of the various connections of single-phase transformers for a three-phase transformation as far as the relative amount of transformer capacity required is given in Table I.

TABLE I—SUMMARY OF THE RATIO OF THE K.V.A. OF TRANSFORMER CAPACITY TO THE K.V.A. TRANSFORMED FOR THE VARIOUS CONNECTIONS

Connection		Ratio
Three transformers	Star connected............	1.0
Three transformers	Delta connected..........	1.0
Two transformers	Open delta connection....	1.15
Two transformers	T connection..............	1.075
Two transformers	T connection (duplicates).	1.15
Three transformers	Interconnected star......	1.075

THE ELECTRIC JOURNAL

INDUSTRIAL APPLICATIONS OF ELECTRIC HEATERS

DECEMBER 1918

Electrically Heated Rubber Vulcanizing Press

In the manufacture of rubber stamps and dies, the procedure is somewhat as follows:—The design or type that it is desired to transfer into rubber is set up in very much the same manner as the type for printing work, and consists of standard type, zinc etchings, wood cuts, etc. The form is placed in a press, and a mould consisting of a plate of soft, damp cement mounted on metal backing for stiffness, is pressed down over the surface. When a satisfactory impression of the type has been made in the mould, the wet mould is placed in an oven and slowly baked until it is dry and hard. This hard mould is then laid face up on the heated bed of the vulcanizing press and a piece of unvulcanized rubber placed on top of it. The head of the press, which is also heated, is then lowered until such a pressure is exerted that the combination of heat and pressure causes the rubber to melt and forces it into the crevices of the mould. Further application of heat causes the rubber to harden and completes the vulcanization. The rubber must then be removed from the press before continued application of heat burns it and causes it to become brittle.

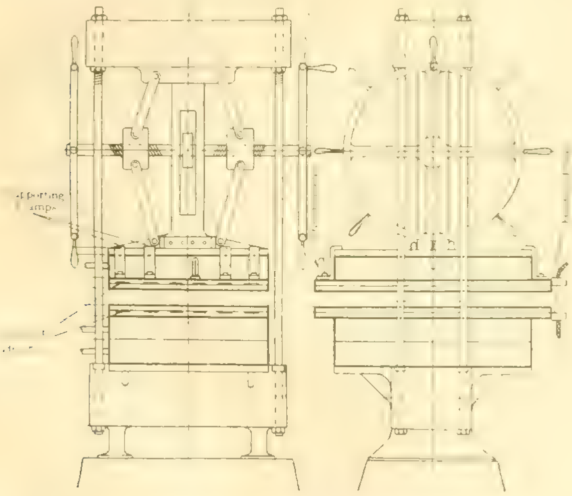

FIG. 1—ELECTRICALLY HEATED VULCANIZING PRESS

The process described above is carried out in presses similar to that shown in Fig. 1, consisting of a lower stationary platen mounted on the bed of the machine, and an upper platen bolted to the head of the machine and capable of being raised and lowered in guides by means of the hand wheel. Pressure is exerted between the two platens by means of a toggle joint. The raising and the lowering of the platen and the application of pressure may be accomplished in any other manner. The press shown has platens 21.5 in. wide, 30 in. long and 1.5 in. thick.

When steam is used to heat these presses, the temperature is limited by the steam pressure. As the upper platen is movable, a flexible steam connection is required which gives considerable trouble due to leakage. Furthermore, it is necessary to keep a special steam generator in operation in summer to supply steam for these presses. The use of electricity as the source of heat overcomes these objections, and, because of the higher temperature, reduces the operating time and increases the production.

When the time for vulcanizing is reduced by the increase in temperature from the use of electric heaters, slight variations in time may easily cause the rubber to become too hard or too soft. Accurate measurements, therefore, become of greater importance than with the steam vulcanizer. It is accordingly necessary to obtain a close regulation of input so that the temperature can be adjusted accurately; to have an accurate temperature measuring device; and to have an accurate time-indicating device.

Regulation of input is obtained through the use of six wide steel-clad heaters in each platen, each heater being 30 in. long by 2.25 in. wide by 0.25 in. thick and rated at 630 watts. The heaters are clamped in grooves machined in the platens, and are connected to two series-parallel knife switches, as indicated in Fig. 2, providing eight different inputs. An accurate temperature measurement is provided by mounting a small thermometer in the top platen with its bulb immersed in mercury contained in a well. An accurate time-indicating device consists of an electrically-operated clock mechanism, provided with an alarm, which is set to signal at any desired interval of time after the clock has been started to operate by an electrical connection made when the platens are brought together.

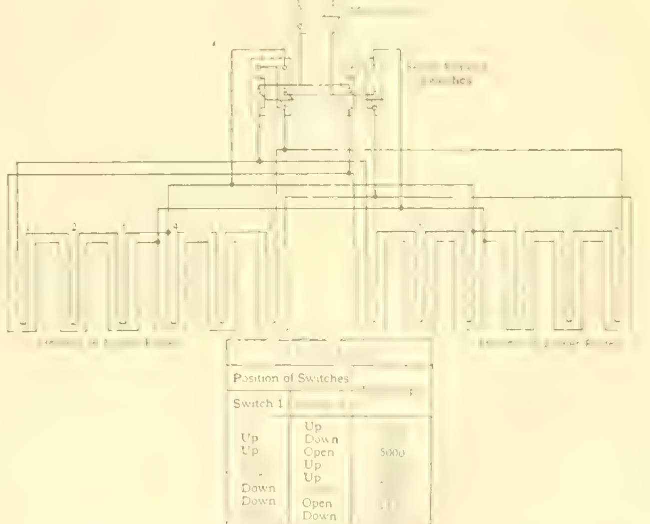

FIG. 2—CONNECTIONS TO GIVE A WIDE RANGE OF HEAT ADJUSTMENT

Actual successful operation of a press, such as shown in Fig. 1, showed an average of 3800 watts required for continuous vulcanizing of rubber forms ranging in size from 2 in. by 1 in. by No. 12 B. & S. gage to 17 by 12.5 in. by No. 7 gage, at an average temperature of 258 degrees F. The time required to complete a form varied from four minutes for the smaller sizes to eight minutes for the largest sizes. The inputs available are shown in Fig. 2. The maximum of 7600 watts will heat a cold press to operating temperature in approximately one hour.

The above data were obtained from an uninsulated press, and since rubber has a low thermal capacity, a much better performance could be obtained from a press well insulated to reduce to a minimum the radiation losses, as practically all the heat supplied is required to overcome the effects of radiation.

The advantages of the electric heat for this application are:

1—Higher temperature available.
2—Closer temperature regulation.
3—Production doubled.
4—Time cut in half.
5—Elimination of leaky steam pipes.
6—Elimination of steam generator in summer.

R. A. Bolze

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

DECEMBER 1918

Maintenance of Traction Brake Equipment

MOTOR DRIVEN COMPRESSORS

Compressors should be inspected and lubricated at regular car inspection periods to guard against air and oil leaks, the entrance of dirt into the compressor, and general improper operation. The best results will be obtained when the oil level is not allowed to fall more than one-quarter inch below the maximum, as determined by the oil fittings. Galena compressor oil is strongly recommended as most suitable. The dirty oil should be drained from the compressor at periods of from 6 to 18 months, depending on the service, and the interior of the compressor thoroughly cleaned with gasoline, draining the gasoline thoroughly before replacing with fresh oil. The interior of the motor should be kept clean by occasionally blowing out and wiping out the motor. Commutators and brushholders should be kept clean to maintain best commutation. Brushes must be free in their holders and renewed in time to prevent wearing to the point where the pressure cannot be maintained by the brush spring on the brush. When commutators become worn to the point where the slotting has been worn away, the commutator should be turned and reslotted.

At periods of general overhauling (at 12 to 18 month intervals), field coils and armatures may well be subjected to a gasoline bath, followed by a thorough drying out and a liberal application of varnish and shellac. Bearings should be maintained, particularly on the connecting rod, to prevent knocking or noisy operation. Valves and valve heads should be thoroughly cleaned. The suction strainer must be kept clean, as otherwise, dirt will be drawn into the motor and compressor bearings and valves are likely to stick or wear rapidly. Strainers should be cleaned at frequent intervals, depending on the service, the more frequently the better. Close attention to this point will give a large return in the matter of decreased maintenance and increased life of the parts.

The compressor should be entirely dismantled and thoroughly cleaned out with gasoline. Particular attention should be given to all wearing parts, fits and adjustable parts, and proper adjustments made to eliminate lost motion due to wear. It is important that the rings and ring grooves be cleaned and that the rings have a good bearing on the cylinder wall and in the groove.

Compressor Governors protected by an air strainer or dirt collector will require little attention other than that incident to the general overhauling. Contacts and fingers should, however, be kept free from burrs, so that any slight burning will not have a cumulative tendency and result in serious damage. Contacts should be kept clean and sparingly lubricated.

Piping—As a precaution against failure, unnecessary compressor operation and waste of compressed air, the piping should be kept tight at all times.

Reservoirs should be drained daily.

BRAKE VALVES

Brake valves should be lubricated at regular car inspection periods. To oil a brake valve, it is necessary first to exhaust the air from the valve. The oil should then be applied through the oil plugs, the valve stem pushed down a few times, and the valve operated to work the oil on to the various surfaces. Lost motion or play between the handle and stem prevents the proper registration of parts and should be eliminated.

AUTOMATIC VALVES

Emergency valves, feed valves and triple valves should be completely disassembled and thoroughly cleaned at regular overhauling periods. The only part of the feed valve requiring lubricant is the slide valve which should be lubricated with dry graphite. In emergency and triple valve, lubricate the slide valve with dry graphite and the piston bushing with a drop or two of oil.

BRAKE CYLINDERS

Remove the nuts from non-pressure head bolts; then remove the piston from the cylinder.

Cleaning Cylinders—Scrape the old lubricant from the cylinder wall and leakage groove and wipe these surfaces clean and dry. Kerosene may be used for assisting in cylinder cleaning, but must be completely removed to prevent serious damage to the cylinder gasket and the packing leather. If the cylinder wall is rusted, the rust should be removed with sandpaper.

Cleaning Piston and Packing Leather—Remove the expander ring from the piston. Scrape all old lubricant from the metal part and packing leather and wipe all surfaces clean and dry. The leather should be carefully examined and should be removed if brittle, thin at any point, cut, cracked or otherwise defective. Do not use kerosene or gasolene on leathers. Examine the piston and follower plate for cracks and tighten up the follower plate nuts.

Applying New Leathers—Examine the follower studs for tightness in the piston. Place the leather centrally on the piston, with the flesh side against the piston. Place the follower in position. Apply the nuts, bringing them into contact with the follower without tightening. Then draw them down uniformly.

Application of Lubricant—Apply a thin coating of brake cylinder lubricant to the wall of the cylinder with a brush. Fill the expander ring groove, at the same time coating the inside of the leather and place the expander ring in position.

Assembling—The piston with spring and non-pressure head should be stood on end with the flat side of the non-pressure head flange and the opening of the expander ring toward the workman. With the piston in this position, enter it into the cylinder. The sleeve or rod should then be slowly raised, and the piston moved into the cylinder until the upper portion of the leather engages the cylinder wall. Form this portion of the leather into the cylinder with a dull edge, round cornered putty knife or similar instrument, while the sleeve or rod is being gradually raised, taking special care not to crimp or otherwise damage the leather. Then pull upward and outward on the sleeve or rod until it is in a horizontal position. Push the piston to its release position and then raise the sleeve or rod to the top of the cylinder to determine whether the expander is in its proper position, which will be indicated by freedom of movement. These instructions for assembling apply particularly when the brake cylinder is in a horizontal position. However, for other positions, the methods employed must be changed as required to produce similar results.

P. L. CRITTENDEN.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest, information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL [illegible] addressed envelope as soon as the necessary information can be obtained. [illegible]

1678—GROUND ON SYSTEM—We have a ground detecting system on the switchboard from bus-bars at 550 volts and of course we cannot find out on which circuit the ground is unless we throw each switch out one after the other. Would you tell me some arrangement to find out which circuit the ground would be on without throwing switch out? There are six circuits at the station.
A.A. (NEW BRUNSWICK)

We see no way of accomplishing this, as all the circuits will be connected when the switches are closed, and the grounding of one circuit would make electrical connection to all other parts. This will be readily appreciated if you make a complete diagram of the circuits and assume a condition of ground on any one of them. F.C.H.

1679—INDUCTION MOTOR OPERATION—(a) A test on a new 20 hp. three-phase, squirrel-cage motor under full load and running at rated speed shows 67, 58, and 62 amperes in the three leads at the same instant. Would like to know what causes such a variation. Should they not be more nearly the same if everything is O. K.? (b) What would be the symptoms if one phase winding in the motor was reversed and also if only one-half or one-fourth of a phase winding was reversed? (c) What is meant when inductance or resistance is expressed in percent? M.F.S. (COLO.)

(a) If everything in the motor is exactly symmetrical, including the air-gap, and the motor is properly wound and connected, the three phases should

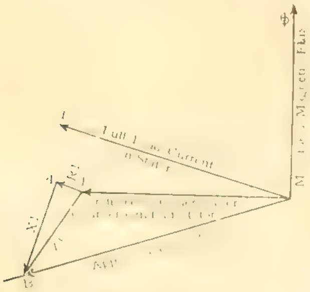

FIG. 1679(a)

balance within narrow limits. In making many combinations of phases, voltages and poles on the same laminated core, it sometimes happens that the number of slots is not an exact multiple of the phases times the poles. This necessitates some slight dissymmetry which is of no real detriment to the operation of the motor but which is noticeable. However it is well always to investigate and make sure there is a real reason for such unbalance. (b) Refer to article in the JOURNAL for Dec. 1917, p. 509. (c) The inductance or resistance itself is usually not expressed in percent but the product of the inductance or the resistance and the full-load current, known as the XI or the RI drop, is sometimes given as a percentage of the voltage generated or induced in the stator winding by the rotating field. This is shown by Fig. (a). The resistance in ohms times the full-load current OI would give the vector EA or the RI drop parallel to OI. The quantity $\frac{AE}{OE}$ = percent resistance drop. Similarly, the reactance in ohms times OI gives the vector AB at right angles to OI or XI drop. The quantity $AB \div OE$ = percent reactance drop. A.M.D.

1680—INDUCTION MOTOR VENTILATING DUCTS—We have a 40 hp, three-phase, 60 cycle, 440 volt, 1800 r.p.m. induction motor, with squirrel-cage rotor. Both the stator and the rotor in this motor have ventilating ducts about ⅜ inches wide in the laminations. The ducts in the stator, of which there are two rows, are in line with those in the rotor. The air-gap in this motor is about 1/32 inches. In every other duct in the rotor there is a thin wedge apparently fastened down in the spider holding the end laminations in place keeping them from fanning out. In the other ducts, the laminations do fan or spread out, break off, get between rotor and stator, and cause considerable damage to stator coils. The laminations in the stator are also found bent over and broken in the same manner. Kindly advise if possible the cause of this trouble, and what steps to take to prevent any more damage to the coils. We have had to rewind the stator once and at present the coils are in such condition that we cannot use the motor. The motor is comparatively new, having been in actual use less than one year.
B.B. (ARK.)

The trouble described is evidently due to faulty mechanical construction, if one may judge correctly from the description. From the data given it appears that some of the ventilating ducts have a "spacer" or "ventilating plate" which stops at the bottom of the slots, as at A in Fig. (a) while the other ducts have a proper ventilating plate with fingers

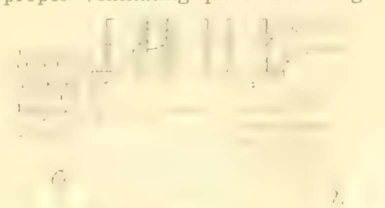

FIG. 1680(a)

extending up to the point B and supporting the tooth laminations. If these teeth are not supported they vibrate back and forth into the ventilating duct and finally break off at the top of A as shown. The remedy would be to take off all the coils and tear down the core and rebuild it using a proper ventilating plate or support with fingers as shown at B. It is not customary among builders of present day standard apparatus to make such a variation between the ventilating plates in the different ducts in the same core, so that it may be this particular motor has a history which accounts for its condition. A.M.D.

168[illegible]—CURRENT TRANSFORMER REGULATION—I have a portable graphic alternating-current, 60 cycle ammeter range, 0 to 5 amperes, that has been calibrated with a portable current transformer. The current transformer ratios are as follows:—Main lead once through the transformer 1600 to 5 amperes, main lead twice through the transformer 800 to 5 amperes, main lead four times through the transformer 400 to 5 amperes. (a) Can I get an accurate full scale reading of 200 amperes by passing the main lead eight times through the current transformer? (b) Does the length of the leads from the instrument to the terminals of the current transformer affect the readings? (c) Will the instrument read accurately if connected up to any standard current transformer, the full load secondary current of which is not more than five amperes? J.A.S. (MINN.)

(a) Yes. (b) Yes. The resistance of the secondary circuit materially affects the current which flows and hence the reading of the instrument. Frequently such instruments are calibrated with special standard leads, and if so, the special leads should be used. If there are no special leads, the resistance of the secondary circuit should be kept as low as possible. The length of the leads has no effect in itself, provided they are of sufficient size to have a low resistance. (c) If the standard current transformer has the same regulation as the special transformer, it can be substituted without affecting the accuracy of the instrument. If it has better regulation, the instrument will read high and, if it has poorer regulation, the instrument will read low. Probably the difference will be negligible. C. R. R.

1683—INDUCTION MOTOR POLES—(a) Is it necessary that the stator and rotor of an induction motor of the wound-rotor type have the same number of poles? (b) With a wound-rotor multispeed motor must the rotor be changed to correspond to the stator? (c) In reconnecting a stator for consequent poles must the rotor winding be changed? (d) What is the effect of operating with a different number of poles in the stator and rotor winding? G.F. (ILL.)

(a) Yes. (b) In general, yes. An interesting exception is described in the JOURNAL for Aug., 1918, p. 310, where a two-speed motor has the secondary winding so connected that certain leads

act as cross-connections for one speed and as short-circuiting connections for the other speed, so that no secondary changes are necessary in changing from one primary connection to the other. (c) Yes. (d) The number of poles (that is the allocation of the flux) is determined by the primary winding. If the secondary winding is not suited to this arrangement of the flux, bucking voltages will be generated in the secondary winding which will seriously impair the operation of the motor. C.R.R.

1684—Current Transformers—We have a customer using about 425 kilowatts at 40 cycles, three-phase, 2300 volts. The current transformers used in connection with the meters for measuring this power are 120 to 5 amperes. We expect within the near future the customer may desire 800 kilowatts and, as the current transformers are not of sufficient capacity to handle this extra demand, the following connection has been proposed, in order that we could use the two present current transformers with two others which are exact duplicates of them and which we have on hand and not in use, in order to properly measure the power on our present meters, using a multiplier of two to get a correct reading. Please advise if the connection in Fig. (a) would give a correct reading on the indicating wattmeter, the ammeter, and the watthour meter if multiplied by two. C.M. (MAINE)

If the 120 ampere to 5 ampere, current transformers are connected as shown with primaries in parallel and secondaries in series, the ratio of the combination will be changed to 240 ampere to 5 amperes and using a multiplier of two will give the correct reading on the meters. A new scale could be very easily made for the ammeter and wattmeter so that the true reading could be obtained directly. The watthour meter however, would require a new gear train to avoid using a multiplier. In making the connections, proper precaution should be taken so that the load will be distributed as evenly as possible between the two transformers. If there is any tendency for the current in the primary circuit to be distributed unequally in the two

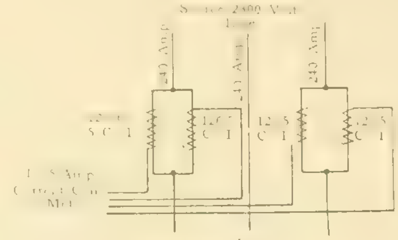

Fig. 1684(a)

branches, this will be opposed by the current in the secondaries, which must be the same in both transformers. This will have the same effect as introducing resistance into the secondary circuit, which will affect the ratio of transformation more or less, depending upon the extent of the unbalancing. It is impossible to operate transformers of large current capacity with the primaries in parallel as suggested, since it is practically impossible to get the current to divide equally in the branches without excessive change in ratio. However, in transformers of the size you mention the operation will probably be quite satisfactory if due precautions are exercised to keep the resistance in the two circuits exactly equal. A.F.D. and W.R.W.

1685—Reconnecting Induction Motors—I have a 35 hp, three-phase induction motor, which is wound single layer, that is to say there are 72 slots and 36 coils. Each side of a coil takes up a complete slot. I desire to rewind this motor and change it to two layers having 72 coils. Would it be necessary to make any changes, such as the span of the coils, or number of turns per coil? Also what is the advantage in winding a stator single layer? E.M. (MO.)

With the two coil per slot winding there is less space for the copper, as it is necessary to insulate between the two coils in the slot, so it may not be possible to get in the slot as many conductors of the same size wire as were used on the one coil per slot winding. If it is possible to get as many conductors per slot as before, each coil should have half as many turns as before, since there are twice as many coils and the throw of the coils should be the same. If it is not possible to get as many conductors in the slots, the number of conductors may be reduced slightly or if the motor is not close on temperature, a smaller size of wire with the same number of conductors per slot may be used. About the only advantage of the one coil winding over the two coil winding is the greater copper space in the slot as stated above. B.B.R.

FIVE YEAR TOPICAL INDEX

OF

THE ELECTRIC JOURNAL

WITH

INDEX TO AUTHORS

FOR

VOL. XI - - 1914
VOL. XII - - 1915
VOL. XIII - - 1916
VOL. XIV - - 1917
VOL. XV - - 1918

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OUTLINE KEY TO TOPICAL INDEX

VOLUMES XI TO XV

THIS Index, as well as the Ten-Year Topical Index, issued as a supplement to the Journal for January, 1914, is arranged according to the topical classification of subjects. The original scheme for this method of indexing was published in the Journal for February, 1906. All articles which have appeared in the Journal since its initial issue can be located quickly by the use of the Ten-Year Topical Index and the present Index, which covers the first five years of the second decade.

Abbreviations: *T*—Number of Tables; *C*—Number of Curves; *D*—Number of Diagrams; *I*—Number of Illustrations; *W*—Number of Words; *QB*—Question Box; *EN*—Engineering Notes; *EH*—Industrial Applications of Electric Heaters; *ROD*—Railway Operating Data. (The numerals following *EN*, *EH* and *ROD* are volume and page numbers.) The main headings and sub-divisions are as follows:—

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